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JOHN M. CLARKE, Director

Bulletin 111

GEOLOGY 13

DRUMLINS OF CENTRAL WESTERN NEW YORK

BY

H. L. FAIRCHILD

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Science Division, October 19, 1906

Hon. Andrew S. Draper LL.D.

Commissioner of Education

Sir: I communicate herewith, for publication as a bulletin of the State Museum, an important paper on the glacial phenomena of New York, entitled the *Drumlins of Central Western New York* by Professor H. L. Fairchild.

Very respectfully yours

John M. Clarke

Director and State Geologist

Approved for publication October 20, 1906

A. S. Draper

Commissioner of Education

MAP SHOWING
GENERAL DISTRIBUTION OF DRUMLINS IN
CENTRAL-WESTERN NEW YORK
H. L. FAIRCHILD
1905

New York State Education Department

New York State Museum

John M. Clarke, Director

Bulletin 111

GEOLOGY 13

DRUMLINS OF CENTRAL WESTERN NEW YORK

BY

H. L. FAIRCHILD

Introduction: general description

Among the varied products of glacial work the smooth mounds and ridges known as drumlins are the most singular. They are the product of continental glaciers by the unique rubbing or molding action of the latter as plastic solids. In their form, attitude, composition and relation they are not only the most remarkable and interesting of the glacial drift deposits but in their graceful outlines and smooth surfaces they are the most striking and beautiful of drift forms, if not of all topographic forms of moderate size. Long before the glacial origin of the drift was established these smooth-outlined hills had attracted attention. They were cited as an objection to the theory of continental glaciation because they seemed inconsistent with the supposed planing and leveling effect of the ice sheet; and even up to the present time they have remained something of a difficulty if not a puzzle. Although the subglacial origin of the drumlins is generally admitted and their constructional genesis conceded, at least in part, the precise mechanical operation in their upbuilding by the antagonistic and balancing forces has not been analyzed. Some of the factors in this complicated problem in glacial mechanics will be indicated below.

The State of New York may claim with confidence the possession of the most remarkable group of drumlins in the world, when all the facts relating to them are taken into account. This drumlin area has been under the writer's observation for several years and the results of the study will help, it is thought, to elucidate the

problem of drumlin formation. It is recognized that no single drumlin area may exemplify all the features belonging to these drift forms, but the New York area includes such a large variety of forms and relationships that it should illustrate the fundamental mechanics and most of the phenomena.

For the reader who may not be familiar with this form of the glacial drift a brief description of its general character will be appropriate. That these hills are of glacial origin is evident from their location always within the glaciated territory, their superficial position and their composition which is compact till or ground moraine, at least in New York. Their molded forms show the overriding effect of the ice and they are believed to have been shaped, if not constructed, under the relatively thin and weaker border of the continental ice sheet, along the zone where the ice in its transporting power became incompetent to carry further its drift burden. Their forms vary from mounds to long, slender ridges; and their size from massive, conspicuous hills, 100 or 200 feet high, to indefinite swells of the drift surface.

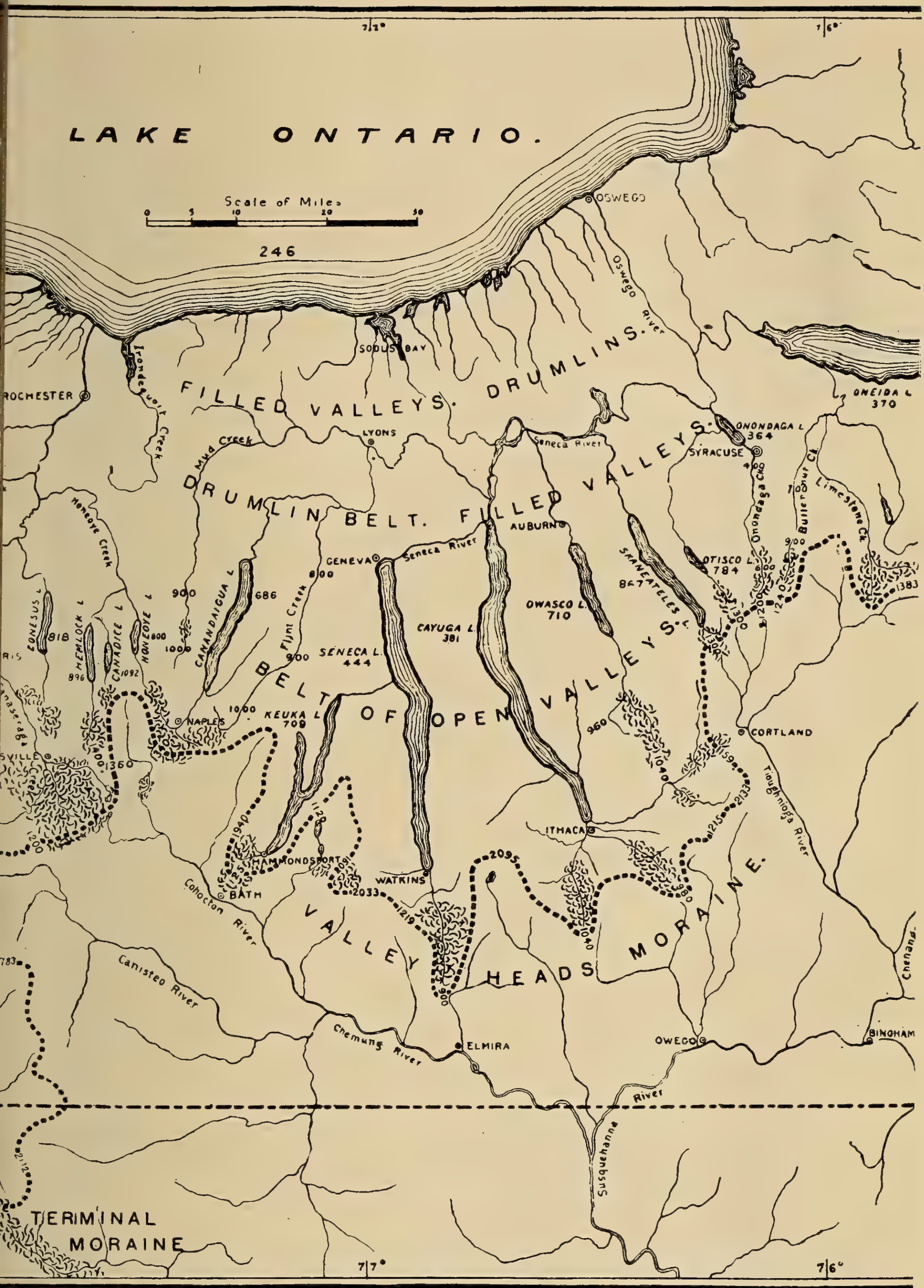
The history of the earlier study of drumlins may be read in the article by W. M. Davis, "Distribution and Origin of Drumlins" [*see* p. 437]; and also in the papers by Warren Upham, specially those of the years 1889, 1892 and 1893 [*see* p. 438]. A brief synopsis of the description by Kinahan and Close of the type drumlins in Ireland is appended as pages 435–36, with a copy of part of their map [pl. 47].

The following names were formerly applied to the drumlin forms: parallel ridges, Sir James Hall, 1815; drumlins, H. M. Close, 1866; parallel ridges, Shaler, 1870; lenticular hills, Hitchcock, 1876; whalebacks, Matthew, 1877; drums and sowbacks, J. Geikie, 1877; parallel drift hills, Johnson, 1882; mammillary and elliptical hills, Chamberlin, 1883.

The name "drumlin" (derived from the Celtic and meaning "little hill") was first applied by H. M. Close in 1866 to these drift hills in Ireland. The various names formerly applied have by common consent given way to the present name, which was introduced in this country by W. M. Davis in 1884

Drumlins are so diverse in their form, and possibly in their precise origin, that any terse definition must be somewhat vague. The smooth form, convex profile and parallelism with the ice flow

Plate 2



PHYSIOGRAPHIC BELTS IN CENTRAL NEW YORK

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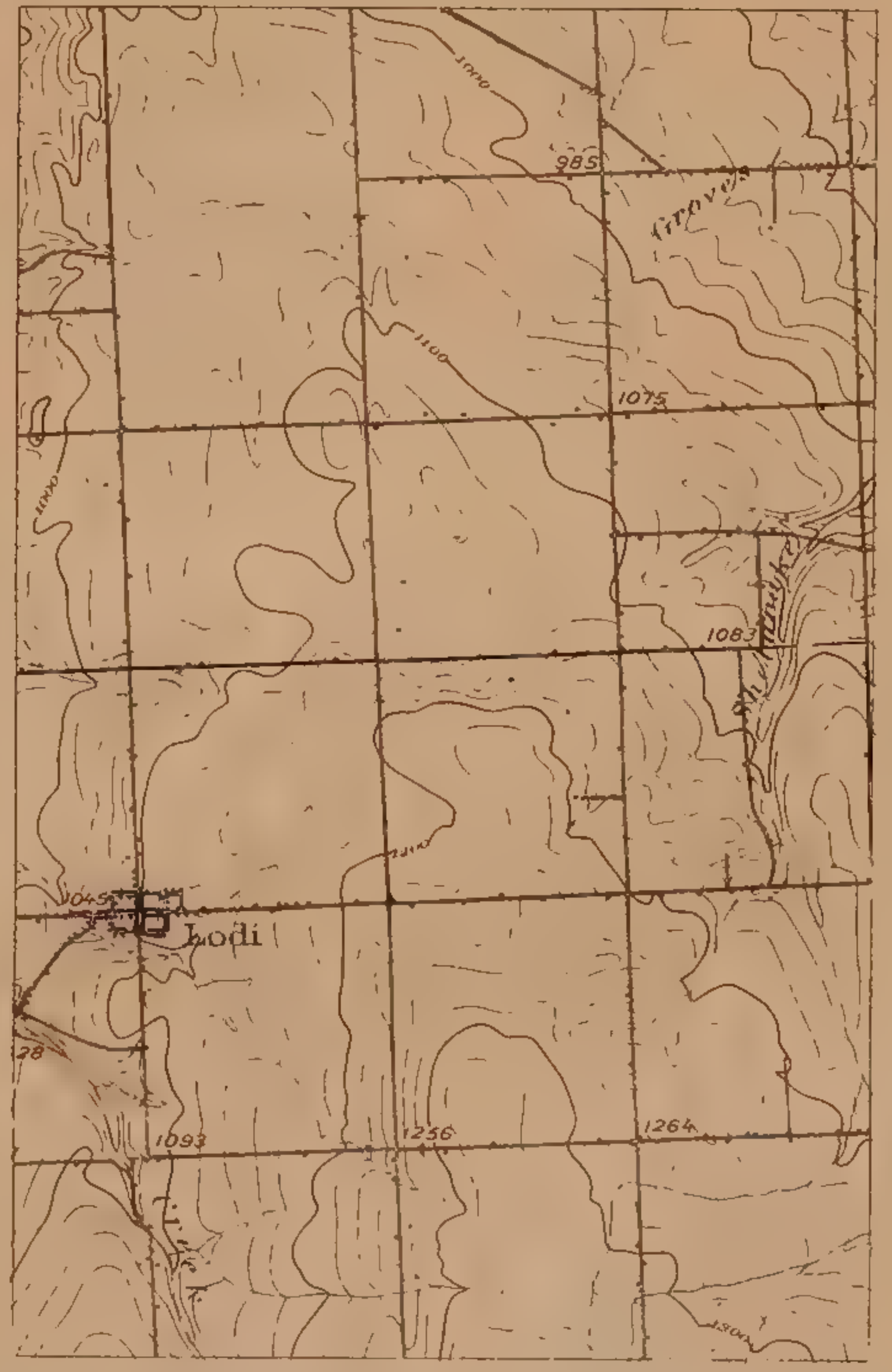
PART OF CHERRY CREEK QUADRANGLE

1. Rock forms; non-glacial.

PART OF OVID QUADRANGLE

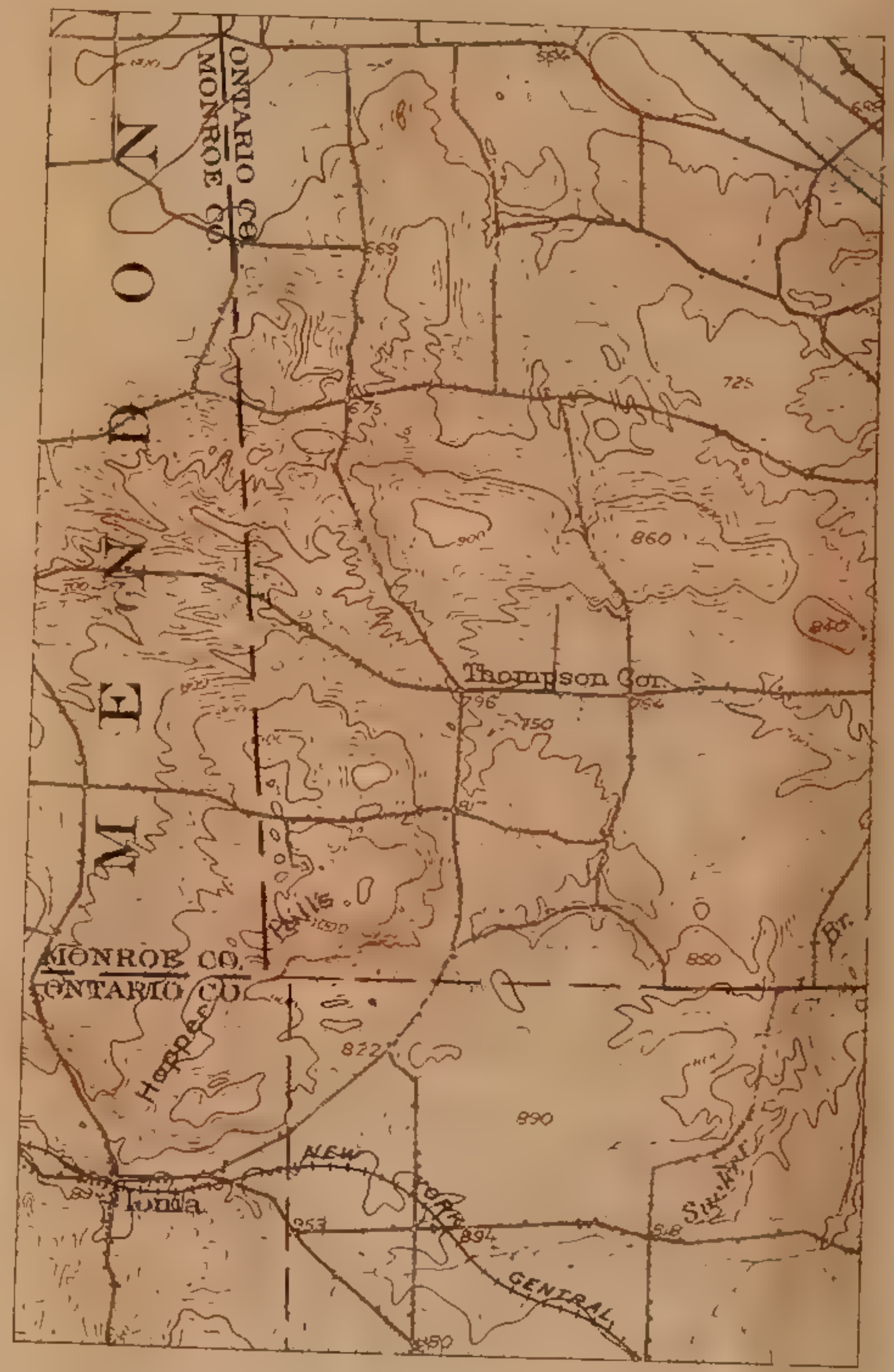


2. Till-covered slopes; expressionless.

PART OF CLYDE QUADRANGLE

3. Drumlins.

PART OF CANANDAIGUA QUADRANGLE



4. Moraine

TYPES OF NEW YORK TOPOGRAPHY

H.L.Fairchild 1905

direction are the striking superficial characters ; but along with these elements the composition and subglacial origin must be recognized. Omitting reference to the precise manner of their amassing, they may be defined as smooth-surfaced hills of till, elongated in the direction of ice movement by the rubbing action of the ice sheet. Or, more briefly, they may be defined as smooth drift hills shaped by ice molding.

The topographic expression of drumlins is so emphatic that any group with fairly developed forms is readily distinguished on maps in 20 foot contours. Plate 3 affords a comparison of drumlinized drift with other forms of glaciated topography.

It appears that the molding effect of the overriding ice was not restricted to the drift masses deposited during the rubbing process by the ice itself, but was felt by moraines or even by rock masses which were exposed to the ice rubbing. The latter effect is seen specially along the summits of the rock ridges that were buried under the glacier [*see* pl. 10]. The name drumlin can not appropriately be applied to ice-shaped rock masses, though the relationship to drumlins may be evident. The term "drumloid" is fully appropriate but the word has long been used in a rather loose and indefinite way for hills of drift having merely a formal and perhaps accidental resemblance to drumlins. A distinctive term with obvious meaning is desirable, and it is proposed to call these forms *Rocdrumlins*, using as a prefix the Celtic word for rock. In the case of ice-worn hills or summits of rock which suggest the drumlin form but do not fully attain it we may use the term *rocdrumloid*.

It should be emphasized that rocdrumlins are an effect of a moderate amount of erosion, or the removal of material, while the drumlins are a product of upbuilding and shaping at the same time [*see* p. 432] The genetic distinction is important.

It seems probable that hill summits of rock should receive under favorable conditions a drumloid expression, that is, a roches moutonné form on a large scale. Plate 16 shows quite as good an example as the published topographic sheets of western New York supply, and even this is somewhat equivocal. Eastern New York can probably furnish better examples. However, it may be said that the erosional work of the continental ice sheet was commonly insufficient, at least in western New York, to strongly mold the hilltops. The absence of such effect is seen in plate 3, figure 1.

Areal distribution

Drumlins have an irregular and apparently capricious distribution over the glaciated territory of Europe and America and over large areas seem to be entirely wanting. None have been reported from Ohio, Indiana, Illinois, Minnesota, the Dakotas, southern Michigan and most of Iowa. They are at least very rare in Pennsylvania and New Jersey. In Maine they are not infrequent but are inferior in numbers and size to those found southwestward.

There seem to be three regions of great drumlin development in the United States. The New England area includes southern New Hampshire, where Upham has mapped nearly 700 drumlins; Massachusetts with 1800, as described by Barton; and a southward extension of the area across Connecticut. The Michigan area includes the eastern part of Wisconsin and adjacent territory in Michigan, where Chamberlin estimates that there are 5000 drumlins; also east of the north end of Lake Michigan in the Grand Traverse district. The third area is the subject of this paper.

Drumlins have been noted in the southern part of Canada by G. F. Matthew, in Manitoba and Athabasca by J. B. Tyrrell, and are said to occur in Nova Scotia.

The drumlins of Ireland are the type forms and are briefly described at the close of this paper [p. 435–36]. Drumlins also occur in the Clyde valley in Scotland, and in the Lake Country of England as described by Upham [titles for 1898, p. 439]. In the low grounds of Switzerland they are said to occur; also in northern Germany on the island of Rügen and east of the lower part of the river Oder. Dr Keilhack has described in the latter area a group of 3000 drumlins.[1] They are said to be disposed radially, facing a looped marginal moraine, covering a belt 6 by 20 to 40 miles.

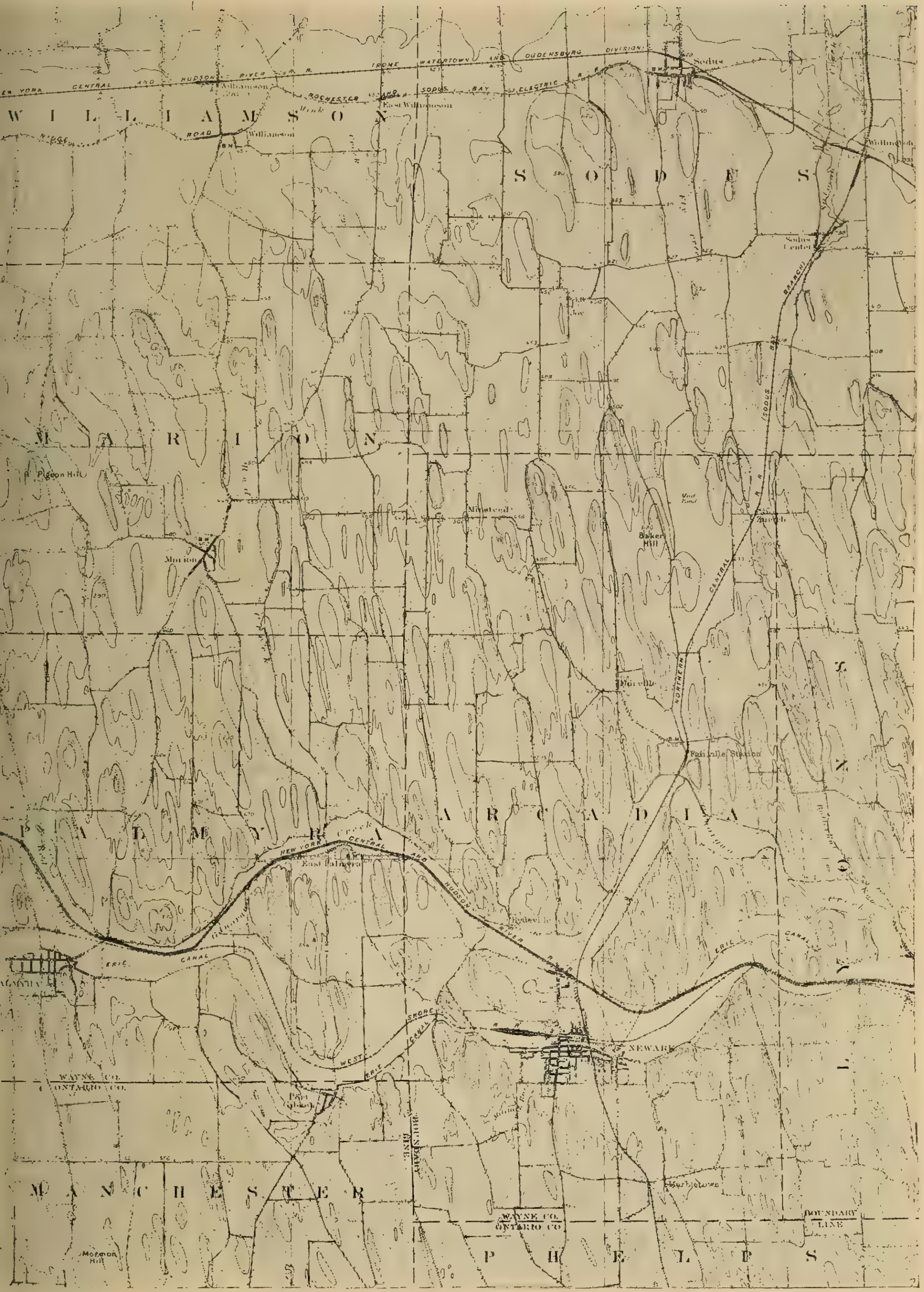
In Scandinavia drumlins have escaped notice, unless certain clay ridges in Sweden, noted by James Geikie,[2] represent drumlinized surface.

When it is recognized that typical drumlin or drumlin ridges are only the most emphatic of a variety of forms produced by the rubbing of ground-contact ice under thrust motion [*see* p. 429], and that on the one hand these forms shade off into indefinite flutings or

1 Keilhack, K. Jahrbuch K. Preuss. geol. Landesanstalt. 1896. p. 163–88.

2 Earth Sculpture. 1898. p. 234.

Plate 4



Palmyra quadrangle. Drumlins on the Sodus-Newark meridian. The south edge of the belt lies on the Phelps quadrangle.

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BULLETIN 111 PLATE 5

PART OF PULASKI QUADRANGLE

H.L.Fairchild 1905

DRUMLINS NORTHWEST OF PULASKI

Showing the varied directions. Only the more prominent forms are indicated.

moldings of the drift, and on the other hand are represented by scoured or rounded roche-moutonnéed rock hills (rocdrumlins), it is probable that this class of phenomena will be found somewhat more widely distributed in the glacial areas than has been supposed. However, the requisite conditions for production of typical drumlins do not seem to have been commonly fulfilled, as vast areas of the glaciated territory seem never to have been subjected to the drumlinizing movement of the ground-contact ice.

The land surface included in the great drumlin area of New York is a belt about 35 miles wide, bordering the south side of Lake Ontario, and about 140 miles long (from Niagara river to Syracuse), with a total area of about 5000 square miles. At least half of this area, or 2500 square miles, carries numerous and well developed drumlins. The eastward extension of the drumlin area swings around the east end of Lake Ontario as a belt 5 to 10 miles wide, reaching past Watertown into the St Lawrence valley. An area in Chautauqua county can not be estimated as the region is not topographically mapped, but the drumlins are scattering.

The New York drumlin area probably includes not less than 10,000 drumlin crests, of which on a conservative estimate at least 6000 are indicated on the topographic sheets. In the districts where the drumlins are close set from 20 to 35 can be counted in a square of 4 square miles. Five drumlins to the square mile is common. Three to the mile can not be more than the average, counting large and small, and on the 2500 square miles of well developed drumlin topography this would give 7500 drumlins. Estimates have been made by counting the separate drumlin summits or crests indicated by the contour lines in certain limited districts and using the figures for larger areas, with a result giving about 5000 crests for the 15 topographic sheets that cover the best parts of the drumlin area. On the 216 square miles of the Palmyra quadrangle [pl. 4] the estimated number of drumlin crests was 800, while an actual count gave 955. Hundreds of minor ridges are beneath the recognition of the contour lines.

The area of well developed drumlins extends eastward around the east end of Lake Ontario, where they are specially interesting on account of their attitude and peculiar form [pl. 5], and reaches westward as far as the meridian of Batavia. The Pulaski, Sacketts Harbor and Watertown sheets show the northeastward ending of

the Ontario drumlin area, while the lower half of the Brockport, Albion and Medina sheets show the westward termination as far as the drumlin forms are indicated by the map contours [pl. 17]. West of the Genesee river and near the Ontario shore distinct drumlins occur, shown in plate 18, where the Iroquois waters were too deep for effective erosion. Westward, on the Niagara-Genesee prairie, the drumlin forms gradually become very elongated and indefinite low ridges, which slowly change to faint, invisible swells dying out farther west. On the sheets toward Niagara the drumlinized character of the surface is suggested only by the obliqueness of the streams and contours to the general slope [pl. 19].

Southeastward the drumlin area terminates in peculiar fashion, forming a decided point at Syracuse. The most easterly drumlins are the conspicuous group southeast of the city of Syracuse, which stand on a base of Salina shales. The map shows no well formed drumlins north of Syracuse, over the Oneida lake depression, nor on the high ground south of the Syracuse district. This extension of strong drumlins as a tongue or point into a district otherwise destitute of such forms is a striking and important fact.

East of Syracuse, as at Fayetteville, Canastota and Oneida, the soft Salina shales which compose the irregular ground surface show no effect of ice rubbing and carry only just enough drift to prove the former presence of the ice sheet. The topography is easily mistaken for morainal, but is due to atmospheric erosion.

Plates 5 to 21 show some groups of drumlins, interesting for either attitude or form, arranged somewhat in geographic order from east to west. The Weedsport [pl. 11], Clyde and Palmyra [pl. 4] sheets show the best display of drumlins, though other sheets exhibit numerous and interesting forms.

In the zones of wave erosion by the glacial lakes the drumlins were cut or entirely removed. Lakes Warren and Dana were too short-lived in the Ontario basin to do more destructive work than cutting notches in the drumlins and building the debris into adjoining gravel spits and bars [pl. 17]. The same applies to Lake Iroquois in its great Cayuga-Syracuse embayment, reaching from Sodus to Richland. But along the continuous or maturer shore of Iroquois, extending from Niagara river to Sodus and from Richland to Watertown, as well as along the living shore of Ontario, no drumlin has been able to stand up alone against the waves;

LONG-RIDGE DRUMLINS AND OVERLAPPING MORAINE

Moraine overlaps and replaces the drumlins on the north. Only the north border of the drumlin area is shaded.

FAIRHAVEN DRUMLINS

These broad ovals are nearer the dome-form than any other group in New York.

although they survived where immersed in more than 30 or 40 feet of water.

At Sodus village the Iroquois beach, the "Ridge road," is an erosion cliff in several strong drumlins. Westward the north border of the Syracuse-Rochester drumlin area swings to the south of the beach and follows about west-southwest to the Genesee river, and thence west and north of west to the limits of the area northwest of Batavia. The following places in order westward lie at the northern limit of abundant drumlins: Sodus, Williamson, Lincoln, Penfield, Pittsford, Churchville, Bergen, Oak Orchard Swamp.

Eastward from Sodus the Iroquois shore with less maturity curves southward around Sodus bay, but still marks a north limit of the close set drumlins. The villages along this border are: South Sodus, Wayne Center, Rose, West Butler, the line passing 2 miles southeast of Wolcott. The northern border of the Syracuse-Rochester area curves so as to lie approximately at right angles to the axial direction of the drumlins.

South and east from Sodus bay, over the Montezuma and Oneida lowlands, the groups of drumlins stood as islands in the Iroquois waters.

East and northeast from Sodus bay a somewhat distinct area of heavy drumlins borders the shore of Ontario; and it is this series which passes around the east end of the lake toward Watertown. The villages of Fairhaven, Fulton, Mexico and Pulaski lie in this area.

Passing lakeward from the Iroquois beach, into what had been deep waters, a belt of drift forms, moraine or drumlins, gradually appears which is abruptly terminated by the present Ontario beach. It would be interesting to know if the waters of Ontario hide drumlins in their depths. As a series of heavy drumlins are opposing the waves all the way from Sodus to Oswego [pl. 7, 8], it seems quite certain that northern members of the group have escaped destruction by submersion in the deeper waters.

The southern limits of the great drumlin area are even less definite than the northern and can not be tersely stated. Approximately they may be given as follows: The western extremity of the area is bounded on the south by the shore of the ancient Lake Warren from Indian Falls to Leroy. From Leroy the drumlins spread south up the west slope of the Genesee valley to Mount

Morris, and extend westward on the high ground (1200 to 1800 feet) past Pavilion, Wyoming, Dale and Linden to Attica. East of the Genesee river the southern limit may be taken as a line joining the south end of Conesus lake with the north ends of Hemlock and Honeoye lakes, the middle of Canandaigua lake and the north ends of Seneca, Cayuga, Owasco and Skaneateles lakes; and thence eastward south of Syracuse to Fayetteville. The villages and cities which nearly mark this boundary are Oakfield, Leroy, then the southwestward stretch to Attica and Mount Morris, Conesus, Hemlock, Honeoye, Middlesex, Potter, Geneva, Waterloo, Seneca Falls, Cayuga, Auburn, Skaneateles, Marcellus, Onondaga Hill, Jamesville and Fayetteville.

In a broad way it may be said that the general area of drumlins covers all the low ground of the Ontario plain north of the Finger lakes and reaches up the north-facing slope to high ground approaching the divide. Between Honeoye and Canandaigua lakes the drumlins lie as high as 1700 feet.

Within the great drumlin area as described above some minor divisions can be recognized With reference both to time and to southern position the first series or group may be designated as the Attica-Geneva series or the western Finger lakes series. This lies on the higher ground and includes the area between the Tonawanda valley and Seneca lake, covering the section of the Genesee valley, and Conesus and Canandaigua lakes as noted above.

The second series, Oakfield-Palmyra-Syracuse, lies on the low ground and includes the central part of the drumlin district and the most striking drumlin topography, with a width in the central part of about 20 miles. On the meridian of Rochester, east of the Genesee river the first and second series are united.

A third and still later series includes the drumlins which border Lake Ontario from Sodus eastward — the eastern Ontario series.

The drumlinizing of the Niagara-Genesee prairie (subsequently the Iroquois lake bottom) was probably contemporary with the second and main series. The complete mapping of the somewhat indefinite morainic belts, a study now in progress, will determine more certainly the time relations of the several drumlin series. Plate 1 shows the distribution as well as it can be portrayed at present.

A separate group of drumlins lies on the high ground about

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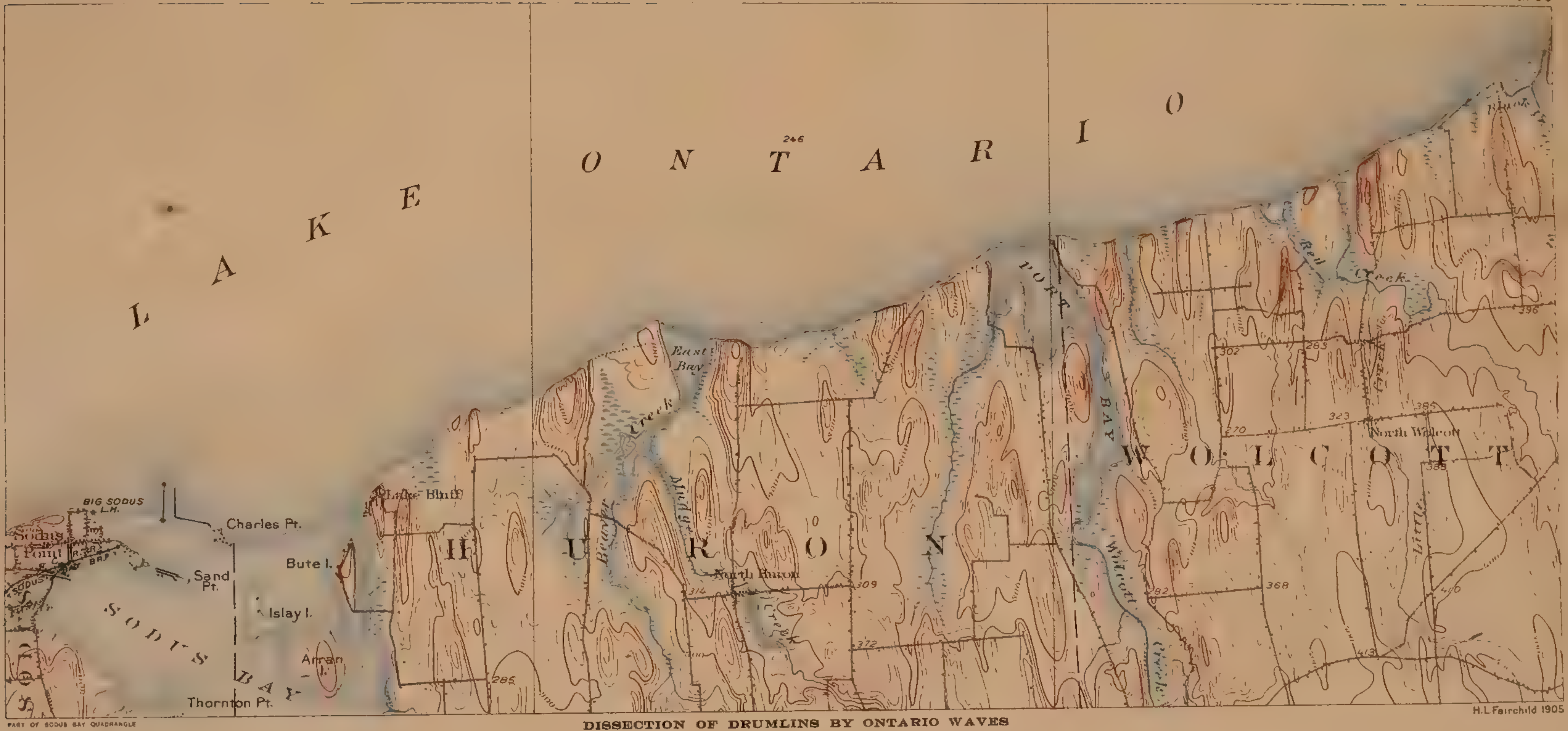

DISSECTION OF DRUMLINS BY ONTARIO WAVES

Chautauqua lake, with direction pointing southeast [pl. 21]. Another group occurs about the north end of Cazenovia lake, with altitude up to 1400 feet. Scattering drumlins occur in many localities, and probably at even higher altitudes than noted above.

The amount of land surface included in the principal drumlin area is roughly estimated as 2500 square miles without including the portion east of Lake Ontario.

Some of the peculiarities of the main drumlin series, the Oakfield-Syracuse, in the matter of definite boundaries and minor grouping should be noted here. These features, though difficult of verbal description, appear very striking on a large map made by joining the topographic sheets. Along the northern border of this series from Sodus east to Irondequoit depression the drumlins are quite abruptly replaced by morainic topography [pl. 15], the relationship being discussed later [p. 424]. The north border of the eastern Ontario series shows the change from drumlins to moraine even more plainly [pl. 6].

On the southern borders the drumlin topography sometimes shades off into smooth drift [pl. 13], while in other districts it is lost in the bolder relief of the rock hills [pl. 16].

The most abrupt ending of the drumlin topography is along the courses of ancient glacial river drainage. A series of drainage channels marks the definite southern limit of the second drumlin series from Victor to Geneva, and on the west of the Genesee at Leroy and Mumford. A later drainage course, from Fairport to Syracuse, traverses the heart of the drumlin series, and seems responsible for the isolation of minor groups, the peculiar forms of which are indicated in plates 9 to 12.

Orientation

The attitude of the drumlins with reference to compass direction varies according to their position in the area. The angular directions of their longer axes cover nearly a half circle. In the district east of Lake Ontario they point east, that is they were shaped by a movement of the ice from the west. As we pass westward around the south side of Ontario we find the direction gradually shifting to southeast, then to south, and finally in western New York to southwest; while on the Niagara-Genesee prairie, in the northwest part of the State, the direction is southwest

by west. This radial direction is shown on the general map, plate 1, and the smaller maps, plates 5 to 17, show the attitude and forms within the 20 foot contours.

The long axes of the drumlins indicate the direction of the latest vigorous movement of the ice sheet in their locality, and the variant directions of the drumlins throughout the whole area prove a radial or spreading flow of the ice mass that rested in the Ontario basin during the stage of waning which is represented by the drumlin formation.

This consonance of the drumlin attitude to the latest ice flow direction is strikingly confirmed by the study of the drumlins in outlying districts. The Chautauqua drumlins point southeast, in harmony with the spreading flow of the Erian lobe of the waning ice sheet. On the other hand, the drumlins of the Watertown district, east of Lake Ontario, point southwest, conforming to the latest flow of the thinning ice in the St Lawrence valley.

Another interesting fact to be noted in this connection is that the axial direction is not always uniform along the same meridian. If the topographic control over the ice movement changed with the varying latitude of the ice front, as the latter was receding, the drumlins record that fact. For example, 20 miles south of Rochester the ice margin was guided by the Conesus, Hemlock and Honeoye valleys and the drumlins are north and south. But on the same meridian, only 6 to 12 miles south of Rochester, the drumlins point to the southwest, the ice margin being controlled by the Genesee valley and the thrust being from the northeast.

The radial or spreading flow of the ice at any single stage must be found by a comparison of the drumlin directions within a single series of drumlins, that is, drumlins which were formed simultaneously. If we take the second, or Oakfield-Syracuse, series we find the axial directions point as follows: At Oakfield, s. 55° to 60° w.; Fairport to Palmyra south; Syracuse, s. 30° e. Taking the third, or eastern Ontario, series, the drumlins are north and south at Sodus bay; at Oswego, s. 30° e.; Mexico, southeast; Pulaski, e. 20° s.; Sandy Creek, east.

A peculiar confirmation of the genetic relation between drumlin attitude and ice-flow direction is found in the Pulaski region. Passing northeastward around the corner of Lake Ontario (Mexico

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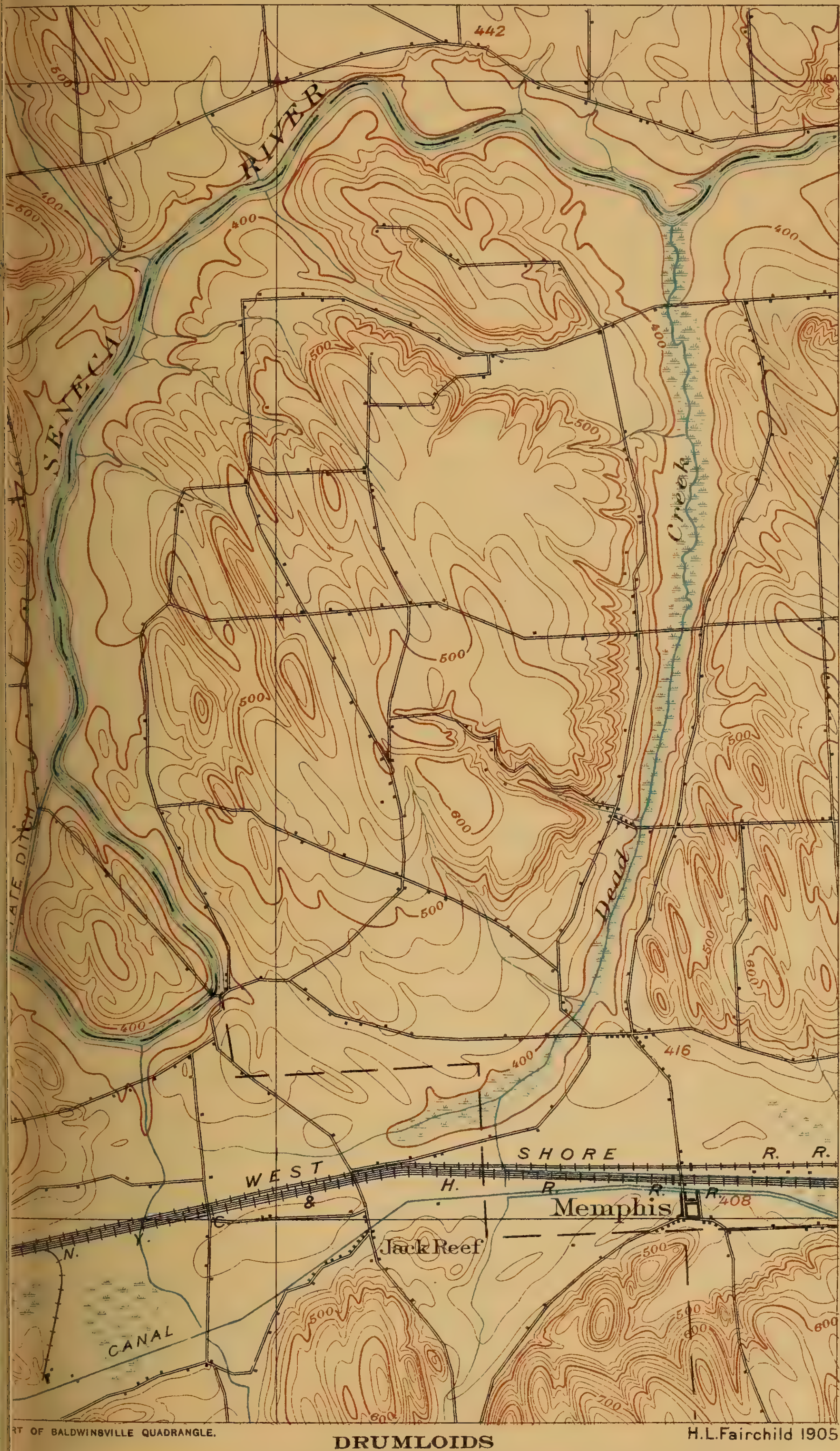
DRUMLINS GROUPED IN ISLAND MASSES

The valleys are carved in Salina shale, which forms at least the base of the drumlins up to 500 feet or higher.



DRUMLOIDS

The drumlin-shaped forms in the upper part of the map are Salina (Vernon) shale.

bay) we find, as noted above, that the direction toward which the drumlins point veers from southeast to east. But as we pass on north some 10 miles, to Ellisburg and Belleville, we find the drumlins pointing southwest, or in direction nearly opposed to the drumlins between Oswego and Mexico.

These opposing directions represent ice-flow movement at different stages of the waning ice body. While the Ontarian mass yet covered the Oswego-Pulaski district the radial flow produced the forms which point southeast at Oswego and east at Sandy Creek. But during the latest stage of the ice in the basin the flow of the St Lawrence valley lobe produced the southwest-pointing forms between Ellisburg and Watertown.

It will now be recognized that if the southeast-pointing forms were made by an earlier flow of the same waning ice mass that produced the later southwest-directed forms then somewhere between the two opposing forms the drumlinized drift should indicate a turning, swinging or pivotal motion of the ice. As a matter of fact the drumlins in the district east of Mexico bay do show the complexity of form and direction required by the theory of ice movement stated above.[1]

Seen in the field, on the ground, the drumlins of the Pulaski district show peculiarities of form which the map contours do not suggest and which are puzzling and apparently inconsistent. The main drumlin forms, as shown on the map [pl. 5], point southeast to east. As seen from the north or south the characteristic profile is usually clear, but with change in point of view, looking from west or east, one sees instead of the expected end view or cross-section profile the peculiar longitudinal profile of the drumlin oval. Many of these contrawise forms should have received expression on the topographic sheets.

From whatever direction we view many of these hills the drumlin form appears. In many cases one detects a faint but distinct molding of the drift in direction highly inclined to the main form. Sometimes an irregular surface which is regarded as morainal becomes equivocal or even decidedly ice-molded with a change in point of view. There are patches of emphatic moraine surface and

1 This is not a case of finding that for which one is looking. The following observations relating to the peculiar forms of the Pulaski drumlins were made and the facts recorded as side notes while making special study of other phenomena, and their significance was not appreciated at the time.

in some areas, as north and west of Pulaski, the moraine character prevails. Frequently a drumlin form as viewed from some distance becomes irregular and morainal in minor relief on nearer view. Sometimes the moraine surface is equally puzzling; smooth ridging or ribbing making one doubtful whether to map the area as moraine or drumlinized drift. Such areas occur southwest of Pulaski [pl. 5] and northwest of Sandy Creek.

One important point which has a bearing on the origin of drumlins should be noted here. The secondary or contrawise forms do not seem to have been made by the cutting or carving of the primary forms but to have been produced by the addition or plastering on of the later form. The work seems to have been constructional, not erosional.

The explanation of these exceptional features would seem to be that the main and larger drumlin forms were made by the eastward motion of the ice; and that the minor molding, at a high angle and usually southward, was produced when the waning ice in this district felt directly the thrust from the St Lawrence valley. It does not appear that the molding of the drift is pronounced in directions intermediate between eastward and southward. Possibly while the ice flow was changing from eastward to southward it was not relatively so vigorous, but it is more probable that only the latest of the minor ridging is conspicuously preserved.

Relation to larger topography

A glance at plate 1 shows that the general drumlin area covers ground of all altitudes from the level of Lake Ontario (and they probably occur in the depths of Ontario) up to about 1700 feet; this highest edge of the drumlin belt lying west of Canandaigua lake [pl 16]. West of the Seneca valley they usually reach up to high ground, 1100 to 1500 feet. In the low north and south depression of the Seneca and Cayuga valleys, where we might expect them to be well developed, they are weak or wanting above 500 or 600 feet [pl. 3, fig 2]. While scattering drumlins may occur in poor form between the eastern members of the Finger lakes it may be emphatically stated that the area of close set and well developed drumlins does not reach south on the high ground east of Seneca lake, but that extensions of the drumlin area do reach up on the high ground west of Seneca lake and as far west as to the

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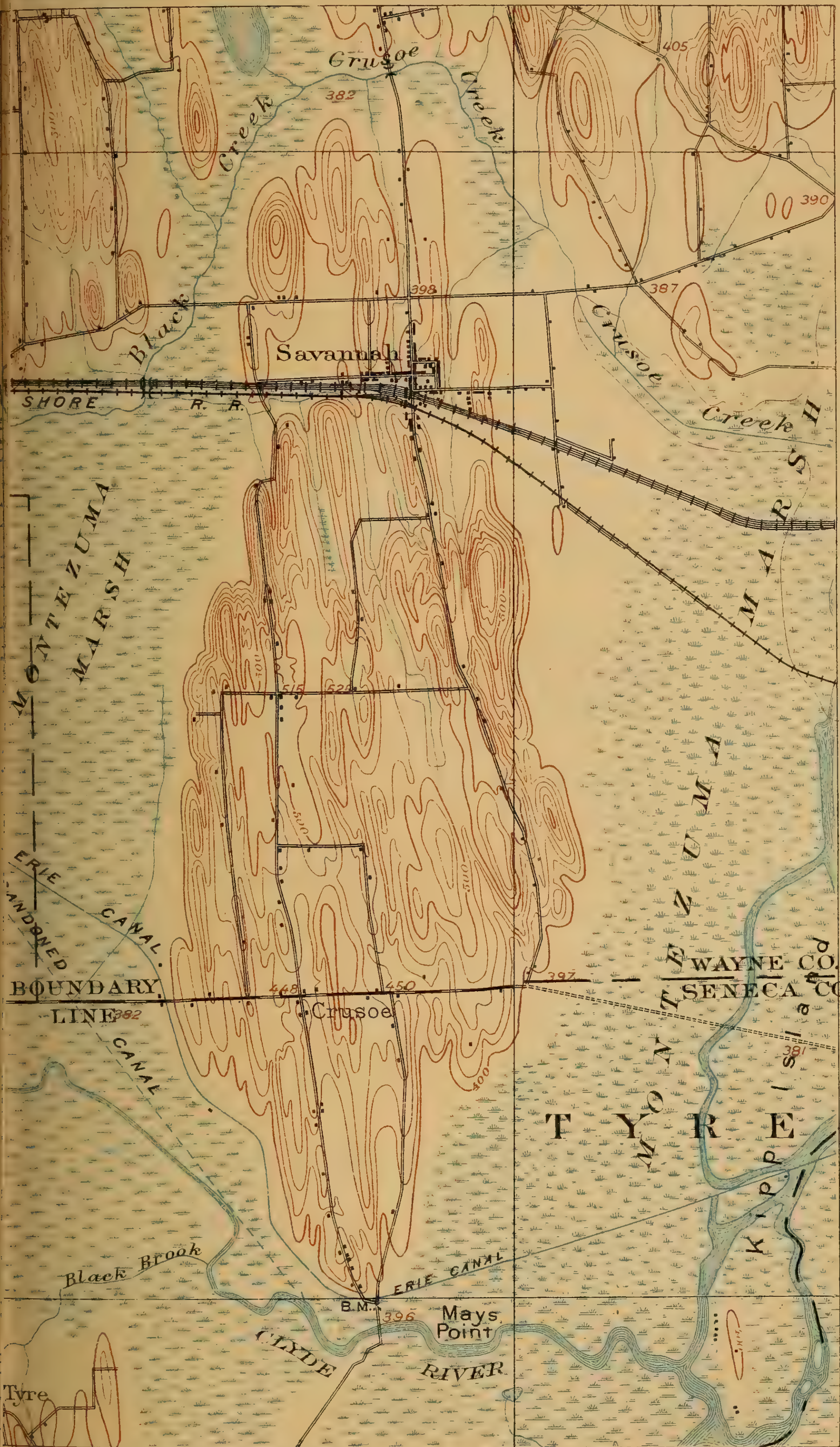
BULLETIN 111 PLATE 11

PART OF WEEDSPORT QUADRANGLE.

TYPICAL OVAL DRUMLINS

H.L.Fairchild 1905



PART OF CLYDE, WEEDSPORT, GENEVA, AUBURN QUADRANGLES. H.L.Fairchild 1905

DRUMLIN MASS IN MONTEZUMA MARSHES

The "heart" of the drumlin area.

Tonawanda valley. This distribution of the drumlins indicates that altitude and grosser topography are not alone controlling factors in the drumlin formation.

The most massive development of the drumlins is on the low ground north of the Finger lakes, and chiefly under 500 feet altitude. This great development of the drumlins on the low Ontario plain and their comparative absence on the higher ground facing the ice sheet is most striking in the central and eastern part of the drumlin belt.

It is important to note that the district of highland drumlins, the western extension of the drumlin area, is where the later ice movement and the drumlin direction coincide with the general direction of the main ice movement, that is, toward the southwest; while the district of no elevated drumlins, east of Seneca valley, is where the drumlin direction is oblique or nearly at right angles to the direction of flow of the thicker ice.

The production or nonproduction of drumlins is believed to depend in part on the abundance and character of the bottom drift of the ice sheet, but chiefly on the active movement of the bottom ice, due to thrust from the rear. The absence of strong drumlins on the gently ascending slopes between Seneca and Owasco lakes may be partly due to the capacious preglacial valleys in the area north of the Finger lakes, which served as catchment for the lower drift. The absence of any large amount of drift, in the form of either drumlins or moraines, in the belt of open valleys [pl. 2] suggests that the last ice which lay on this territory was comparatively clear of drift. It would seem that the greater burden of drift had been either rafted over the level of the open valleys to the higher valley heads moraine farther south, or was held in the lowest ice, and built into the drumlins farther north.

As stated above [p. 369] the land surface east of Syracuse never felt the rubbing action of the ice sheet. The Syracuse district was subjected to the thrust of a tongue of ice pushed southeastward from the spreading Ontarian mass. The southeastward and southward flow was not sufficient to reach the land surface over the Oneida lake region nor over the high ground east of Seneca valley. However, the land surface west of the Seneca valley, lying where the latest ice movement was the same as the principal ice movement,

toward the southwest, felt the molding effect of the ice thrust during the waning stage.

Relation to underlying rock strata

A glance at any stratigraphic map of New York State will show that the dominant drumlin area, north of the Finger lakes, lies on the low ground north of the outcrop of limestones formerly called Helderberg and Corniferous and over the belt of strata now known as Cayugan (Salina), Niagaran and Oswegan (Medina), naming them in descending stratigraphic order, or from south to north. These strata are chiefly shales, with relatively thin limestones in the Niagaran and some sandstone beds in the Oswegan.

The following table gives the approximate thickness of the several strata along the Cayuga meridian (corrections supplied by Mr C. A. Hartnagel of the State Geological Survey).

New York rocks along the Cayuga meridian

Divisions		Thickness in feet	Kind of rock
Erian	Hamilton	1 140	Shale
	Marcellus	80	Shale
Ulsterian	Onondaga	80	Limestone
Oriskanian	Oriskany	3	Sandstone
Cayugan	Manlius, Rondout	70	Limestone
			Limestone
	Cobleskill	6	Limestone
	Salina	1 400	Shale
Niagaran	Lockport, Rochester	320	Limestone
			Shale
	Clinton	80	Shale and limestone
Oswegan	Medina	950	Shale and sandstone
	Oswego	200	Sandstone
Cincinnatian	Lorraine, Utica	820	Shale
			Shale

The drift supply for the drumlins of any district was derived mainly from the strata immediately northward. The above table shows that rocks beneath the limestones which inclose the Oriskany are mainly shales of great thickness. Counting the Medina as one fourth sandstone and the Niagaran as half limestone we have 3130 feet of shale, 200 feet of limestone and 440 feet of

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BULLETIN 111 PLATE 13

PART OF CLYDE AND GENEVA QUADRANGLES.

H. L. Fairchild 1905

SOUTH EDGE OF THE MAIN DRUMLIN SERIES

The terminal moraine lies in front of the attenuated drumlin border.

PART OF PALMYRA AND PHELPS QUADRANGLES.

H. L. Fairchild 1905

DRUMLINS OF THE MORMON HILL GROUP

The south termination is abrupt against a glacial river channel.

sandstone. All these strata have a decided southward dip which gave outcrops projecting northward against the ice advance. By long eras of preglacial weathering these exposures of shale and limestone afforded a large supply of plastic drift to the bottom ice. It is believed that the rock rubbish was not in any stage of the ice work carried far away, but on the contrary was plastered into the drumlin masses. The thick clay strata supplied a burden of unusually clayey and adhesive drift; and it seems probable that the adhesive and plastic character of the lower drift was a contributory factor in the upbuilding of the drumlins, specially the taller ones.

Form and dimensions

These elements are very variable. The ordinary shape of the drumlins in western New York is an elongated oval, the length being three to five times the breadth. Occasionally they are short ovals, and rarely approach the mammillary form, but much more frequently they are long or attenuated ridges. The elongated or ridge form is the characteristic New York type, though other forms occur frequently, except the dome.

Considering horizontal dimensions the several types may be distinguished as the mammilla or dome; the oval; the slender oval or short ridge; and the linear or attenuated ridge. The two latter forms include the great majority of New York drumlins. It is an important fact that the several types are not intermingled but are separately grouped, certain districts exhibiting some particular type almost exclusively. This is fairly illustrated in selections from the topographic sheets; the oval form, large and small, being shown in plates 7 and 11, the Fairhaven, Syracuse and Weedsport districts; plates 12 and 14 showing the short ridges in the Clyde-Palmyra district; while the long ridges are shown in plates 6 and 19, the Oswego district and the Niagara-Genesee prairie. The very slender, linear ridges are often too low or weak to be shown by 20 foot contours, but an example which appears on the map is here given as plate 13, the district north of Waterloo and Seneca Falls.

The lengthwise profile of the shorter drumlins is an elegant curve, convex to the sky, and characteristically more abrupt or steeper at the north end. The crest line of the longer ridges is commonly almost a straight line, which appears to the eye as true as if cut to a "straightedge" [pl. 30]. The south ends of all drumlins,

except the steeper ovals and domes, taper off into the general sheet of till unless eroded by waves or other agency.

In cross-section the variation of profile is more limited than in longitudinal section. The summits naturally have a symmetric curve. Unsymmetric but yet convex summits may be produced by the drumlin process, but sharp crests, as in plates 29, 34 and 36 are regarded as an effect of later erosion. In some cases the erosion of the sides of the drumlin has gone so far as to gnaw into the summit and produce a scalloped or wavy or broken crest line. As a rule the shorter drumlins have the flatter cross-section profile, while the long and the linear ridges may have either a crest curve of short radius with steep side slopes or a broad summit and semicircular cross profile.

The junction of the convex drumlin with the horizontal ground surface naturally gives a concave slope at the drumlin base. Above this concave basal slope all drumlin surfaces are regarded as normally convex, and departures from convexity are due to some interference with the constructive process or to some subsequent effect. Two or more drumlins may overlap, or blend, or even be superposed [*see* p. 409] so as to produce irregular or unusual forms. Morainal drift is frequently banked against the sides and bases of the drumlins so as to change the true form. Erosion by the waters of glacial outflow may have cut the slopes and even the crests of drumlins, but decided crest cutting has been infrequently seen in New York, though conspicuous in Massachusetts.[1]

Vertical ridging or ribbing of the side of the drumlin is thought to be positively erosional, either by glacial waters or by postglacial storm wash and weathering. On the other hand longitudinal fluting or molding is regarded as a constructional effect of the drumlin-making progress.

With very few exceptions the drumlins are cleared of timber and their surfaces are under cultivation, as they afford the best soils. Some of the minor irregularities of surface may be subdued by the farm cultivation, but when the elements contributing to their erosion are considered it is remarkable that they are so well preserved. In the great majority of cases they seem to preserve their original form with practically their natural surfaces.

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1 Barton, George H. Glacial Origin of Channels on Drumlins. Geol. Soc. Am. Bul. 6: 8–13.

PART OF MACEDON QUADRANGLE.

H.L.Fairchild 1905

WALWORTH DRUMLINS

Moraine drift is scattered among the drumlins, wholly replacing them on the north. The Iroquois beach ("Ridge road") forms, by erosion, the north limit of the moraine.

The type of form least exemplified in New York is the dome-shaped. While such may rarely be found they certainly do not characterize any district. The group of drumlins which most nearly approaches the mammillary form, judging from the topographic sheets, lies in the neighborhood of Fairhaven bay, and is partly shown in plate 7. The oval form is excellently shown on the Weedsport sheet [pl. 11]. The long oval or short ridge, the "dolphin back" shape, probably includes a majority of all the New York drumlins, and is the most widely distributed. A massive development may be seen on the Palmyra sheet, plate 4. Probably this form should be regarded as the typical drumlin form, from which the dome on the one hand and the linear ridge on the other are extreme variations.

The long drumlin ridges, which are specially pronounced in New York and are therefore regarded as the New York type, are well displayed on the Clyde, Auburn, Oswego and Brockport sheets. There are two extreme varieties of the ridge form, the large and the small. The large form includes broad, low swells or rolls which if lying alone or far separated may not be recognized as of drumlin nature. They are not often indicated by the map contouring. These low, broad moldings of the till are the common and only form over most of the surface of the Niagara-Genesee prairie. Passing west on the Rome, Watertown and Ogdensburg Railroad, the change can be readily seen from quite typical long drumlins near the Genesee river [pl. 18] to very long swells of low relief, which if not at all indicated by the 20 foot contours may be recognized by the shallow cuts for the railroad grade. Westward these rolls gradually fade into gentle undulations of the surface, quite imperceptible except by the up and down grades of the railroad. Large areas are perfectly flat to the eye. Buildings are visible for miles in different directions on the plain unless hidden by trees. The roads stretch great distances, ending to view only by the overarching shade trees or by a turn in direction. That this smooth country has been ice-molded is shown by the stream flow, which is northeast or decidedly oblique to the general slope. The low relief and the oblique stream control is well shown in plate 19.

These southwest-pointing drumlin ridges occur in strong development southwest of Alden and west and southwest of Buffalo over

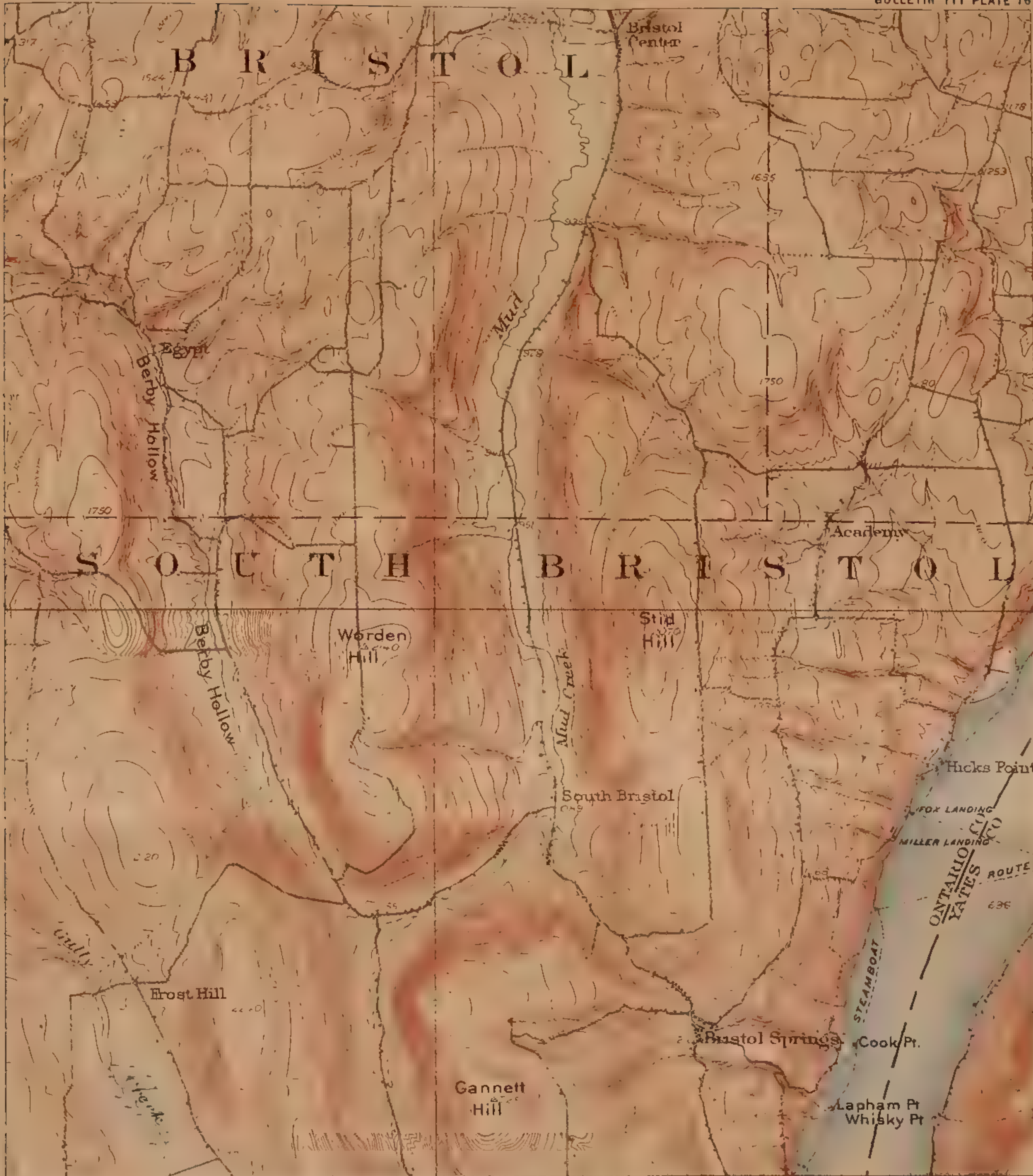
the lower and smoother plain. The contouring on the Erie county sheets, the Attica, Depew, Buffalo, and other quadrangles to the south, fails to properly indicate the drumlinizing of the land surface. As the ridges lie in the smooth country occupied by the glacial Lake Warren and the subsequent falling waters, and as they have the southwest direction parallel with the general contours and the lake shore lines, some of the smaller ridges are liable to be mistaken, in distant view, for huge wave-built bars or beaches.

The small variety of the long ridges is displayed in the Lyons-Clyde-Savannah district, where the primary drumlins include between them a secondary or minor order of ridges. These inferior ridges are straight, parallel, side by side, and often not larger than large railway embankments. They are not good subjects for photography but plates 32 and 33 are examples. These attenuated, intermediate ridges prove the molding action of the ice, and its drumlin-making tendency, even in the hollows between the larger structures. The major and minor ridges taken together suggest comparison with a piece of wood molding "struck" by the planing machine. This comparison is even better if we take the drumlins which exhibit longitudinal ribbing or fluting along their sides or bases. This longitudinal molding on the slopes of drumlins is certainly constructional and not due to any subsequent or erosional effect, as are the vertical forms.[1]

To the observant traveler on the railroads between Rochester and Syracuse the statement that the longitudinal drumlin profile is always convex seems untrue, because decided concave notching may be seen on both north and south ends of the drumlins. These are due to subsequent wave erosion by glacial lake waters. Some work of this kind was done at higher levels by the Warren and Dana waters [pl. 17], but the most conspicuous notching is in the area of the Iroquois waters. The pronounced erosive work illustrated on the shore of the living Ontario [pl. 7, 8] and along the "Ridge road" or ancient shore of the extinct Iroquois [pl. 4] may be seen in less degree but yet clearly between Lyons and Syracuse from the trains of the New York Central and the West Shore Railroads. Plates 36, 37 and 39 are views taken from the railroads.

1 Speaking of these ridges D. F. Lincoln has said: "From this they grade downward to little ridgelike elevations of 5 feet in hight and a furlong in length. Even these are quite distinct to the eye, rising from the uniformly level plain."

ly ... are crowded



PART OF CANANDAIGUA AND NAPLES QUADRANGLES

H.L.Fairchild 1905

HIGH-LEVEL DRUMLINS BANKED AGAINST THE BRISTOL HILLS

The great Bristol hills are hard rocks and quite unaffected by the glacier. The drumlins southwest of Bristol Center are probably the highest above sea in western New York.

This wave cutting of the drumlins which held their heads up as islands in the Iroquois waters seems capricious. Some drumlins which from their location must have been exposed to severe wave impact from the direction of the heaviest winds (mainly northwest) exhibited little effect, while others [pl. 38] which had more sheltered positions or were exposed only to southerly winds are decidedly cut. The amount of wave cutting seems to have depended in no small degree on the composition and texture of the till.

One singular effect of the end erosion of the isolated drumlins is to give a bent appearance to the cut end. Oblique erosion of the originally rounded end causes the crest line of the ridge to bend away abruptly, to the leeward, from the axial line of the hill. In some cases this change in the direction of the crest line is the best evidence of erosion, for it is believed that the original crest of the "stoss" or struck end of the drumlin must have been true to the axial line. Examples of these twisted-nose drumlins are rather poorly shown in plates 36 and 37.

A singular form of drumlin is found in the district south and southwest of Rochester, illustrated in plates 40 to 42. This suggests one drumlin superposed on another; a sort of two-story drumlin. They were first noted in connection with the search for evidences of Dana waters. Some of the concave slopes coincide with the Dana level and possibly the features have been rarely accentuated by wave erosion, but the form is found at other levels. Moreover, the surfaces of the two-story drumlins have the characters of ice molding, the lines are out of horizontality, and erosional characters wanting. The form is believed to be the product of the ice work, and perhaps due to two stages of the constructional process, or to a slight change in the direction of the ice movement.

These double-deck drumlins have been found only in the district at the north end of the larger Genesee valley, and on either side of the valley. It is suggested that the variation or change in the upbuilding process which caused this peculiarity in form may have been related to a change in the direction of ice flow due to the influence of the Genesee valley on the thinning ice sheet.

The cross profile of a drumlin is naturally subequal or symmetrical, but there is modification of the slopes when two or more drumlins lying close together, either side by side or in echelon, are crowded

in their growth or even blended. Asymmetry may be due to some local variation in the ice movement, apart from the crowding in construction.

Sometimes the drumlins have an outline when seen endwise that resembles the normal longitudinal profile. This abnormal form has been seen frequently in Wayne county west and northwest of Walworth [pl. 15]. This form is not due to change of ice flow direction (which accounts for the similar appearances in the Pulaski district) but to irregular construction, and perhaps to ultimate union of primarily distinct drumlins. In the dominant drumlin area the growing drumlins seem to have frequently fused together so as to give unbalanced cross-section profiles, but such drumlin masses have in longitudinal outline the characteristic curve.

Dimensions. The size and dimensions of drumlins are variable, within limits, according to the quantity and quality of the drift and the depth and impulse of the ice sheet. The smaller or infantile drumlins do not usually have good or characteristic forms unless they are of the slender type or small, attenuated ridges, which may be small in cross-section and yet retain a distinctive character as ice-molded till.

There seems to be a limit to the hight of individual drumlins, this being in New York about 200 feet. Using the map contours for determining the base of the drumlin as well as the summit altitude (an inexact basis, with maximum error of 40 feet) only one drumlin is found with altitude over 200 feet. At some point the upbuilding process is antagonized by the eroding or leveling tendency and a balance is struck between the opposing forces which limits extreme hight, and results, apparently, in the production of multiple ridges of moderate size instead of one huge ridge. This principle seems to be illustrated in the orm of the peculiar groups in the Syracuse region, described later [p. 429 and pl. 9].

The most conspicuous drumlins, striking because of their isolation, like those rising out of the Montezuma marshes, are not the highest. Using the map contours, as noted above, for approximate data along with the figures frequently given on the map for definite altitudes of many higher drumlins, the following table has been compiled. This gives the approximate altitudes of base and summit and the individual hight of a considerable number of New York drumlins in different districts.

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BULLETIN 111 PLATE 17

PART OF ALBION QUADRANGLE.

H.L.Fairchild 1905

ELBA DRUMLINS

The northern drumlins bear the gravel spits and wave-cut cliffs of Lake Dana, at about 700 feet. At about 880 feet, on the south edge of the map, is the shore of Lake Warren.

Altitude and hight of highest drumlins

Designation	Base and summit altitudes	Hight
Meridian of Rochester		
Rider hill, 2 m. n.w. of West Rush	620-800	180
Huckleberry hill, 2 m. w. of Lima	900-1054	154
Jakman hill, 2 m. n.e. of Livonia	1040-1194	154
? hill, 1 m. n.w. of Livonia	920-1080	160
Meridian of Palmyra and Macedon		
Pigeon hill, 2½ m. n.w. of Marion	480-665	185
Triangulation station, 4 m. s.w. of Canandaigua	1040-1201	160
? hill, 1 m. n. of Palmyra	480 633	150
? hill, 2 m. n.e. of Palmyra	500-670	170
[1] Mormon hill, 4 m. s. of Palmyra	600-700	100
Meridian of Sodus-Newark		
Triangulation station, ½ m. w. of Sodus	440-595	155
Triangulation station, 1 m. s.w. of Sodus	460-620	160
Zurich hill, 5 m. s. of Sodus	440-640	200
Baker hill, 6 m. s. of Sodus	460-680	220
Triangulation station, 2 m. s. of Clifton Springs	700-860	160
Meridian of Sodus bay-Clyde		
Chimney bluff, 2 m. e. of Sodus bay	250-400	150
? hill, 1 m. n.w. of Rose	420-600	180
Triangulation station, 2½ m. s. of Clyde	420-600	180
Meridian of Fairhaven		
? hill, 2 m. n.e. of Fairhaven	250-400	150
? hill, 4 m. s.e. of Montezuma	520-700	180
Meridian of Oswego-Weedsport-Auburn		
Triangulation station, 4 m. n.w. of Cato	400-567	167
? hill, 3 m. n. of Cato	440-620	180
? hill, 3 m. w. of Cato	420-600	180
? hill, 4 m. n. of Weedsport	440-620	180
Triangulation station, 2 m. s. of Weedsport	600-740	140
Meridian of Fulton-Jordan-Skaneateles		
? hill, 2 m. s. of Jordan	660-800	140
Cottle hill, 3 m. n.w. of Skaneateles	880-996	116
Region of Syracuse		
? hill, 3 m. n.w. of Camillus	700-860	160
? hill, 2 m. n.e. of Camillus	640-760	120
Triangulation station, 3 m. e. of Camillus	660-799	140
Triangulation station, 3 m. e. of Camillus	580-736	156
? hill, 3 m. s.e. of Syracuse	660-805	145

1 It is a singular coincidence that the celebrated drumlin, the "Mormon hill" [pl. 29, 30], in which Joseph Smith claimed to have found the golden plates of the *Book of Mormon*, should have as its altitude the centennial multiple of the sacred number seven, in English feet. The hight of the hill was not known until the recent topographic survey, but the Latter Day Saints may claim that their prophet had inspired knowledge or divine guidance.

It will be noted that only two drumlins in the above table lift their summits 200 feet above their platform, though several approach that hight.

The length of the drumlins is quite as variable as their hight, but it can not be well determined from the map contours, as a relief of less than 20 feet may carry a distinct ridge for a long distance. The long ridges of drumlinized drift which specially characterize the drift surface in the northwest corner of the State, including the Niagara-Genesee prairie, are almost unrecognized by the topographic map.

Scores of drumlins can be found on the map with a contoured length of a mile, or even a mile and a quarter. A length of 1½ miles is not rare, but 2 miles is extreme. Perhaps the longest well contoured forms are in the Oswego district, shown in plate 6.

The very long drumlins are sometimes produced by the close welding of overlapping ridges.

Composition and structure

The material composing the New York drumlins is very compact till. The writer recollects only one or two instances in which water-laid drift has been found unequivocally incorporated in the drumlin mass. Gravel and sand are frequently found on the flanks of the drumlins, specially where they were exposed to wave work of the glacial lakes, but the experienced observer could never mistake this for drumlin material. Water-laid drift may be expected on the surface of the drumlins as an occasional product of superficial stream work at or near the ice border. In morainal areas the marginal drift, kame or till, may be scattered on and among the drumlins, and sometimes in such abundance as to obscure or perhaps partially bury the drumlin forms. Such a case is found in the Junius kame moraine, midway between Geneva and Lyons. However, this superficial morainal drift must not be mistaken for nor confused with the drumlin material, as it is not only emphatically distinct in its genesis from the subglacial drumlin mass but subsequent in time of deposition.

Only two instances have been found by the writer of water-laid drift distinctly within the drumlin mass. In the northeast edge of the village of Lyons, on Phelps st., a small drumlinlike ridge of till about 500 feet long and 150 feet wide, lying on the east flank of a

ICE-MOLDED, OR DRUMLINIZED SURFACE

East end of the Niagara-Genesee prairie. The drainage shows the direction of the ridging. Iroquois waters reached south to the Ridge road. Compare plate 18

larger drumlin ridge, has 15 feet depth of till over a base of sand; but the sand substratum is restricted to the small ridge.

In a recent extensive examination of the internal structure of drumlins, to be described below, a bed of sand was found in the interior mass of a drumlin, situated 2 miles northeast of Fairhaven bay and south of Juniper pond. The waves of Lake Ontario have dissected the drumlin obliquely, exposing a section of till about 100 feet high. About midway in the hight of the cliff is an irregular layer of sand, 2 to 3 feet thick and of considerable but indefinite extent. The sand shows no clear bedding and seems to have been crushed and worked over by the ice rubbing. The extreme rarity of such inclusions of water-laid drift in the drumlins of New York is a conclusive argument against the theory that they are erosional forms, produced by overriding and reshaping of terminal moraines. This point will be discussed later.

The drumlin till, specially in the deeper layers, is decidedly more compact and harder than the ordinary sheet till, and the included stones of all sizes are more generally abraded. The material gives evidence of movement under pressure; it is emphatically the glacial grist.

The proportion of crystalline and far-brought material is apparently less than in terminal moraine deposits, but examination has not been sufficiently thorough to indicate percentages. In any belt it will probably be found that the proportion of material derived from the subjacent strata or the rocks immediately northward is larger in the drumlins than in the moraines. In other words, drumlins represent, at least in central New York, the subglacial or "ground moraine" drift.

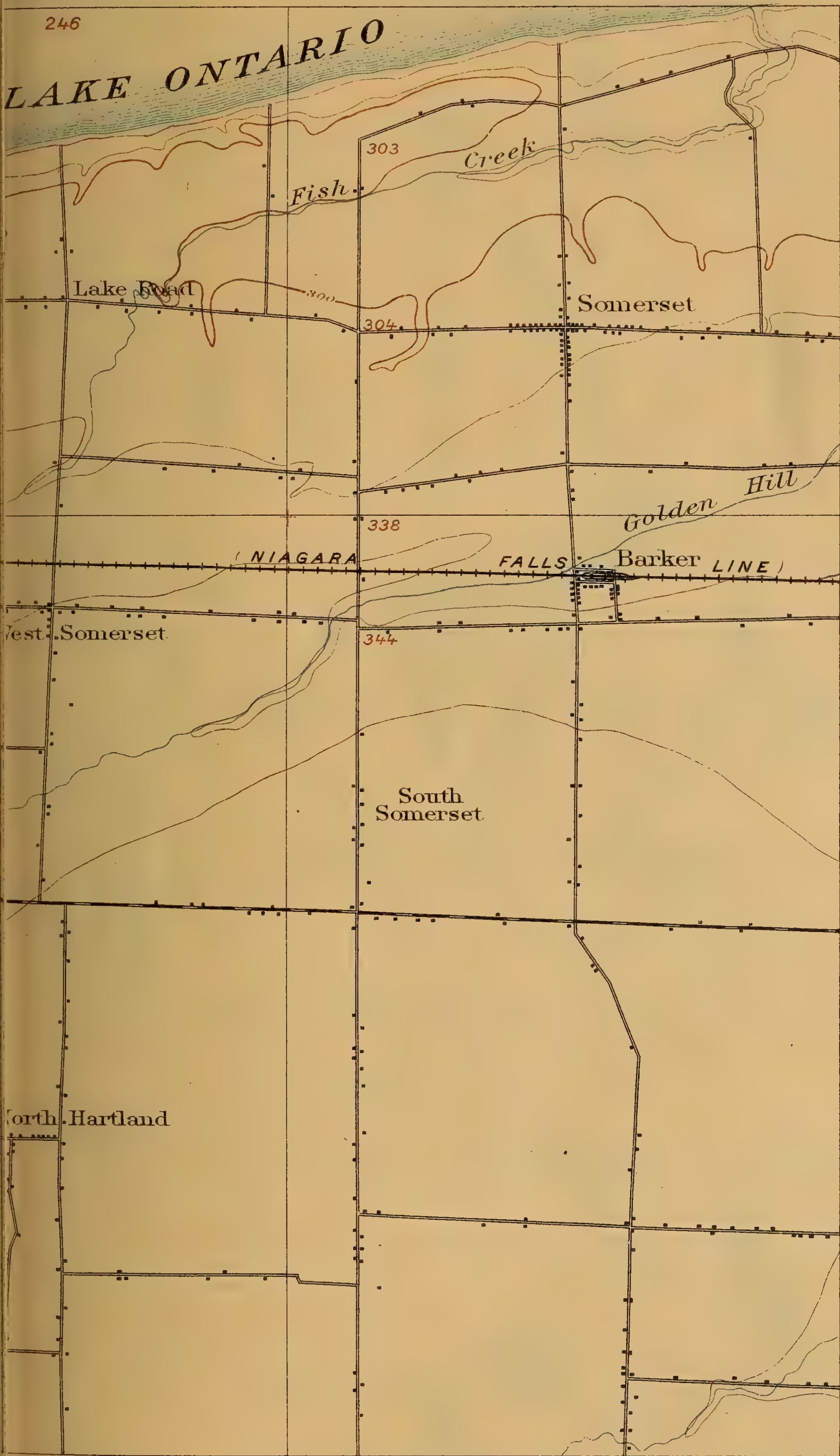
Rocdrumlins. Between Palmyra and Syracuse the foundation of the drumlins is Salina shale, mostly the soft red and green beds called Vernon shales. All the deeper valleys are cut in this shale, which may be seen on the slopes as bare patches of bright colors, red and light green. An excellent exposure may be seen at the "blue cut" on the south side of the West Shore and the New York Central Railroads midway between Newark and Lyons; and at the time of this writing (September 1905) the electric road building in that district is making many exposures. At the "blue cut" the Vernon reaches 60 feet above the railroad, or to the hight of about 480 feet, judging from the map contours. In the region of

Jordan and Memphis these shales forming the walls and bottom of the broad valley are eroded into forms simulating morainal topography. (This resemblance of the shale erosion forms to moraines is very pronounced all the way east to Oneida, and even the experienced geologist who is new to the region will make wrong diagnosis if he decides by the forms as seen from a distance.)

In the Jordan-Memphis district the Vernon shales reach up over 500 feet, while the lake and stream fillings in the valleys are about 400 feet altitude. The Vernon shales, therefore, extend upward about 100 feet above the lowlands and are overlain by the somewhat harder but yet soft gypsum-bearing Camillus shales. East of Jordan they form the common platform from which the drumlins rise [pl. 9, 10]. But west of Jordan, as far at least as Newark, the drumlins are situated much lower, their bases being contoured [pl. 11, 12] by the 400 or 420 foot contour, and many rising out of the Montezuma marshes as if partly buried under lake deposits. It appears, therefore, that in the Weedsport-Lyons belt the Vernon and Camillus shales belong in the same horizontal plane or topographic horizon as the drumlins, and the interesting and important question arises if the drumlin forms may not be partly shale instead of till. Some study of this problem has been made with definite results. The drumlins show only till at the surface, in nearly all cases. Often this may be only a veneer or varnish of drift rubbed into the soft shale. The West Shore Railroad has several good cuttings through drumlins in the stretch west of Port Byron which ought to reveal interior composition and structure, but the cut slopes are so coated with wash from the upper material that to casual inspection they appear as till.

One and one half miles northeast of Port Byron the red Vernon shales appear clearly on the slopes and at the summit of a drumlin-shaped hill having a summit contour of 460 feet. This hill is indicated in the lower left hand corner of plate 11. Here we certainly have a drumlin form in rock, a rocdrumlin. It is very likely that other of the lower drumlin forms may be chiefly shale with only a veneer of drift, and it is more than likely that some of the larger drumlins have a base or core of shale.

All the western central New York rocks have a decided southerly dip. It is evident, therefore, that north of the Syracuse-Lyons parallel the strata should lie at increasingly higher elevation.



PART OF OLCOTT QUADRANGLE.

H. L. Fairchild 1905

DRUMLINIZED SURFACE

Near the west end of the Niagara-Genesee prairie. *Compare plate* 18. The ice-molding carries the streams oblique to the slope. Surface smoothed by Iroquois waters.

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BULLETIN 111 PLATE 20

PART OF CALEDONIA QUADRANGLE.

H.L.Fairchild 1905

GENESEE VALLEY DRUMLINS

The attitude of the drumlins shows how the later ice flow in the Genesee valley was diverted from the general southwest direction. Not all the drumlins are indicated.

The vertical or stratigraphical range of the Vernon shales, which are several hundred feet in thickness (the thickness of the whole group of Salina shales is about 1400 feet, *see* page 404) would include the whole hight of all the drumlin forms in a considerable belt of territory. An examination was made of the hills west of Baldwinsville with a result not unexpected. It was found that all the drumlin forms are clearly composed of red shale, with only an apology of till covering. All the hills in the upper half of the map, plate 10, and lying between the two north-leading valleys are known to be not drumlins but rocdrumlins.

At first sight these hills would be regarded without question as true drumlins, but there are decided though refined differences which appear on closer study. The rocdrumlins are not so symmetrical as the till forms; the slopes are less regular; and the struck ends are liable to be more abrupt and irregular and with less convexity. The differences are clear when once recognized, and are fundamental. The 20 foot contours of the map even reveal a difference. Looking at plate 10 it will be noted that the bases of the hills are indefinite, and that as hills they do not possess the strong individuality of the drumlins, as shown in plates 11 and 16, for example.

These Vernon shales are only hardened clays, without structure and very easily decomposed.[1] They yield more readily to weathering and probably to erosion than any other rock, and the product of the ice rubbing was doubtless a lubricant and plastic paste essentially like clayey till in its mechanical properties. In consequence the hills of Vernon shale which stood within the zone of drumlin formation, in the conflict with the moving ice, were more easily shaped into the drumlin form than other rocks, but when given that shape they resisted the ice impact better than harder rocks. These shale hills were at the same time more compliant and more resistant. They became drumlins in effect though not in origin. They are erosional forms, while drumlins are constructional forms.

The soft Vernon shales extend westward through the State but nowhere appear so prominently at the surface as in the region described above. Eight miles south of Rochester they are exposed at about 570 feet altitude. It is apparent that along their east and

1 The rapidity with which these shales weather to mud was the cause of dispute and litigation in the matter of the deepening of the Erie canal a few years since. The contractors justly regarded the shale as "rock" and charged for rock excavation; but inspection a few months later found the spoil banks to be only clay rubbish.

west outcrop they have been eroded by weathering and ice rubbing and the belt of outcrop deeply covered with drift. Their more common appearance on the Newark-Syracuse parallel is partly due to greater thickness and also to the postglacial excavation by the ice border drainage. The Salina shales as a whole, many hundreds of feet in thickness throughout the drumlin area, have supplied a large amount of plastic and adhesive material for the drumlin construction process, and may be one factor in the production of the drumlins.

Concentric bedding. If drumlins are constructional forms, that is, were built up by a plastering-on process, then it should be expected that on cross-section they would reveal some concentric bedding or onion structure, with the upper layers parallel to the drumlin surface. Theoretically the bedding need not be conspicuous as there could not have been great variation in the constructive process, as compared with the work of water, in either kind or quality of material or in rate of deposition. The comparative uniformity in the work of the ice, taken in connection with the heterogeneous character of the till, would seem unfavorable to any conspicuous structure.

Few cuttings in drumlins expose large sectional areas, and such as do occur can commonly be seen only at close range, which is unfavorable to inspection of indefinite and large-scale structures. To recognize the general structure it is necessary to have a comprehensive view, yet not so distant as to obscure all details.

Bedded structure in drumlins has been casually noted in a few instances but the only description of such feature (in the writer's knowledge) has been given by Upham, of a few drumlins on the Massachusetts coast at Scituate and in the neighborhood of Boston, which have been dissected by wave erosion.[1]

The most favorable exposure of interior structure of drumlins known to the writer is found along the south shore of Lake Ontario, and specially between Sodus bay and Oswego. In this stretch of about 28 miles not less than a score of drumlins, many of large size, are dissected to their core by the wave erosion. The constant undercutting by the waves [pl. 8, 43–46] yields continually fresh sections from top to bottom, and fortunately in different directions. Some drumlins are cut in direct cross-section; some in oblique

1 *See* titles on page 438 for the years 1888, 1889 and 1892.

UNIVERSITY OF THE STATE OF NEW YORK

STATE MUSEUM

PART OF DUNKIRK QUADRANGLE

H.L.Fairchild 1905

CHAUTAUQUA DRUMLINS

This area was molded by southeastward flow of the later ice, spreading from the Erie basin.

section ; and some in longitudinal section. One could not reasonably ask for more favorable exposure than nature here affords.

The structure can not be seen properly at close range from the beach, nor at the long range from the steamers. In August 1905 the writer secured the help of an oarsman and with a small boat examined the entire shore from Sodus bay to Oswego. Part of this stretch was reexamined in September, and the study carried westward from Sodus bay. Many photographs[1] were taken, some of which are produced in plates 43 to 46.

The erosion cliffs range in hight from 20 feet up to 140 feet The growth of vegetation is rarely sufficient to obscure the structure, and in some cases is in itself a proof of the till bedding, as it lies in horizontal lines. The higher cliffs are all bare.

More than half of the cliffs show undoubted concentric bedding and in several it is surprisingly distinct. At distances which minimize the relief of the cliff faces, in buttresses, reentrants, and amphitheaters [pl. 43], the fact of bedding parallel with the drumlin surface is strikingly evident, and is shown in different ways. A difference in the texture of the beds is apparent even at close range. Distinct zones or lines of boulders are often seen. A difference in shade of color is common, and the shading due to varying capacity for moisture is pronounced. The latter is also shown by patches of vegetation clinging along certain zones. The second cliff east of Sodus bay, "Cline's bluff," shows at even 2 miles distance a conspicuous line of vegetation. A most striking proof of bedded structure is shown by the differences in weathering, which are often indicated, as in plate 46, by the uniformity in hight on the cliff face of the conical buttresses. Two other cliffs which show this feature well are: one east of Juniper pond and 2 miles east of Fairhaven bay, which shows three lines of erosion cones ; and

1The first photographs were taken with an ordinary shutter which proved too slow with the tossing of the boat. These first photographs show clearly the bedded structure but they are too blurred to be suitable for reproduction. For the second trip the Bausch & Lomb Optical Company kindly loaned a "Plastigmat" lens and a "Volute" shutter, and the photographs of plates 43 to 46 represent an exposure of 1-150 of a second, in the hazy light of the last day of September. The camera was a 5x7 Cartridge kodak, the only camera which the writer has used in six years.

When these views were taken the drumlin sections were very dry and the hygroscopic differences in the till layers did not show as well as they do soon after a heavy rain. Much better views can be obtained when all conditions are favorable, as quiet water of the lake, good lighting and the cliff faces in best condition.

To Mr W. R. Walsh of Sodus Point the writer's thanks are due for valuable assistance.

another a mile northeast of the mouth of Eighteenmile creek and about 5 miles southwest of Oswego.

In cross-section view the concentric bedding decreases in convexity passing downward toward the bottom of the drumlin. In other words, the bedding near the base of the drumlin is quite horizontal or slightly arched; and the arching increases with hight until near the top the layers are parallel with the drumlin profile. In some instances, particularly toward Oswego, the sections exhibit a superficial bed, estimated at 10 to 20 feet thick, of a lighter color and yellowish shade, and apparently less compact than the deeper blue-gray till. This superficial bed weathers into smoother or more uniform faces, instead of the projections, pinnacles, towers, or battlemented forms of the deeper and harder till.

A good test, and a confirmation, of the concentric structure is found in the oblique and the nearly longitudinal sections. A glance at plates 7 and 8 will show how the lake erosion is cutting the drumlins at very different angles. It is found that the stratification exposed in these different sections has the direction which would correspond to a concentric bedding. In sections approaching the longitudinal the bedding is quite straight and declines parallel with the crest of the drumlin toward the tail of the hill. In general the upper beds are parallel with the cliff profile and have the curvature appropriate to the angle of the section.

The application of these facts of drumlin structure to the problem of drumlin origin will be found in a later chapter. To facilitate the study of the subject by any one who wishes to examine the drumlin sections for himself the following notes and directions are supplied.

West of Sodus bay (the Pultneyville sheet) the cliffs are partly morainal and only two good drumlin sections occur, one of them being shown in plate 46. East of Sodus bay the lake shore is included in the Sodus bay sheet, reproduced in plate 8, and the Oswego sheet, partly shown in plate 7. These maps show approximately the angle of the wave cutting with reference to the drumlin axes.

The drumlins which display the bedded structure in the clearest manner are, taken in order eastward: Lake bluff (using the local names) [pl. 44]; Cline's bluff, 1 mile east of Lake bluff; Blind Bay bluff, 1½ miles east of East bay [pl. 45]; two cliffs either side of Juniper pond, which lies 2 miles beyond Fairhaven bay; and the

Plate 22

Drumlin 1 mile west of Lily Dale. View looking east

Plate 23

Drumlin 1 mile south of Lincoln, Wayne co.   View looking south of west

Plate 24

Wayne county drumlins, town of Walworth. Looking west from Freeville hill

two cliffs midway between Eighteenmile and Rice creeks, southwest of Oswego.

The best longitudinal sections are the one east of Juniper pond and the one halfway between Eighteenmile and Rice creeks. The lighter colored top layer is well shown in the three cliffs east of Port bay.

It should be understood that the distinctness of the bedding varies with the degree of moisture and the lighting; and that it may be subject to change with depth of cutting and so vary with time.

Formation: theoretical mechanics

Thus far this writing has been of a descriptive character with only a modicum of reasonable inference. It is now time to take up the philosophical side of the study and if possible explain the origin and manner of making of the drumlins. In the earlier writings on these structures the question of their genesis naturally received much attention, but without confident conclusions. Probably no geologist doubts their glacial genesis but the precise manner of their formation has been in question. Two general views have been held, one that they are overridden and reshaped moraine drift, the other that they are constructional forms, built up ab initio by the moving ice out of its ground moraine or interglacial drift. That they received their form by the molding effect of the overriding ice sheet seems too evident to be questioned.

The idea that drumlins were primarily moraine masses may be true of some drumlins, and possibly of some forms in New York; but it certainly does not apply to them in general. The distribution of the drumlins is not in accord with the theoretical location of any former morainal belts; and this conception takes no account of isolated drumlins in some regions, or groups of drumlins far removed from suggestions of other drift masses. Moraine deposits are expected to lie in continuous belts. Furthermore, no moraines of such breadth and quantity of drift as are held in the Rochester-Syracuse drumlin area are found in New York, probably not in the Eastern States.[1]

1 It should be admitted that the full history of the ice work in New York and New England is doubtless more complex than we now realize, and that probably there was ice invasion with its attendant frontal waters previous to the Wisconsin epoch. We now see the deposits as the last ice sheet left them, and while we must take the phenomena as we find them and study them as they lie we must not ignore the probability of an antecedent and different condition. However, it would be unscientific to minimize the facts before us and magnify the unknown or theoretical features.

Considering the great volume of water-laid drift commonly associated with the New York moraines, amounting in many cases to almost the entire mass, it would seem certain that the drumlins in the same territory, if overridden and reshaped moraines, should frequently if not habitually hold sands and gravels as a part of their mass ; in other words they should have the irregular structure and miscellaneous composition of the moraines. Indeed it would seem likely that with the volume of deep-seated waters in the marginal portions of the ice sheet (the streams either subglacial or in deep trenches) aqueous deposits might not infrequently be left beneath the ice in such position as to be incorporated into the drumlin mass. However, as stated above [p. 412], this feature is remarkably rare. Drumlins may be built on other antecedent drift, and stream or lake deposits may occur on their surface, but the drumlin material in the area under discussion is very compact till, and may be distinctly bedded.

The facts pertaining to the drumlins of New York are only consistent with the theory of their constructional origin. And now we have the sufficient proof that at least a great number of them were slowly built up by a plastering-on process, as described above [p. 416].

Since we know that the Sodus bay-Oswego drumlins are constructional it is a legitimate assumption that other drumlins in contiguous areas have the same origin. In the further discussion of the New York drumlins their constructional origin will be assumed.[1]

In the theoretical discussion of the mechanics of drumlin construction three sets of factors are recognized : (*a*) those pertaining to the ice itself, (*b*) those relating to the drumlin-forming drift, and (*c*) the external influences of topography and climate. These will be briefly considered in the above order.

a Dynamic factors pertaining to the ice body

1 *Vertical pressure*, which is directly proportionate to the vertical thickness of the ice sheet.

2 *Horizontal pressure.* At the periphery of the continental ice sheet the horizontal pressure necessary to produce flow on level

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1 Since these lines were written it has been found that sections of drumlins in Oakfield cemetery, Syracuse, exhibit excellent bedding.

Plate 25

Wayne county drumlins. 3 miles north of Walworth. Looking east of south

Plate 26

Drumlin 1 mile east of Elbridge. Looking south of east. Same point of view as in plate 27

Plate 27

Drumlins north of Elbridge. Endwise view. Looking west of north. Same point of view as in plate 26

ground or on an up slope (as in the New York drumlin area) was mainly an effect of the vertical pressure in the deeper and rearward part of the mass. The depth of the ice sheet along the drumlin-making zone was probably insufficient to greatly aid the forward movement; but to the degree that plasticity was effective the vertical pressure might have had some effect in modifying the movement or in producing differential flow.

3 *Vigor and velocity of flow.* This is due primarily to the thrust from the direction of the deeper ice. The horizontal displacement or mass movement of the ice would be influenced by the larger features of the land surface and by the local temperature and rainfall [see *c*].

4 *Differential flow.* The practical plasticity of the ice would theoretically seem to allow unequal flow, or a tendency to flow in prisms or currents analogous to stream currents; and the drumlins are evidence of such local variations in the ice work.

5 *Plasticity.* This property of glacier ice would probably be increased by pressure, heat and water supply as a lubricant. In the marginal, drumlin-forming zone of the ice sheet plasticity due to vertical pressure would be reduced, that due to horizontal pressure would be fairly constant, while that due to heat and rainfall perhaps would be increased.

b Factors relating to the drift held in the ice

1 *Volume of the drift.* It has been recognized that plastic flow of glacier ice diminishes with increase of rock debris. But the movement of the lower ice by rearward thrust would not be so greatly affected by the contained drift. The influence of the drift toward rigidity might assist in producing differential flow in prisms or bolts. Whatever might be the effects on the flow of the ice by variation in the load of drift its abundance in the lower ice would seem to be a direct aid to drumlin building.

2 *Position of the drift.* The vertical location of the rock rubbish in the ice seems an important factor. Debris superficial to the ice sheet could only produce morainal masses. Drumlins must have been built from the debris carried in the lower layers of the ice.

3 *Quality of the drift.* It would appear that a clayey, adhesive character of the drift would facilitate the plastering on process, by which the New York drumlins are certainly made. No drumlins are found composed largely of boulders and friable material.

c Factors of external control

1 *General land slope.* A down slope would favor movement of the ice both by thrust and by plastic flow of the upper over the lower layers. An up slope would probably retard or prohibit motion at the bottom except by thrust. The great drumlin area of New York has an up slope, but the dominant minor area is nearly level. The Chautauqua drumlins are on high ground, very irregular but broadly level.

2 *Minor topography.* This factor is indefinite and uncertain because variable in many ways. It would seem that great irregularity of the overridden land surface would be unfavorable to movement of the lower ice, and the drumlin-making motion would lie more in the plane of the hilltops. (This has a bearing on the construction of the Syracuse island masses, page 425.) Small prominences in the bed of the ice sheet might be favorable as nuclei for the initiation of drumlins.

3 *Temperature and water supply.* Plasticity of the ice would be favored by heat and water. Cold and dryness favor rigidity. The margin of the ice sheet must have had nearly the highest possible temperature and the largest supply of lubricating water, from rainfall and ice melting. This would be quite independent of latitude as the ice can not be warmed above the melting point.

It is apparent that the drumlin-building process involves many factors, and most of them indeterminate. The problem is exceedingly complicated, including not only the difficult subject of the behavior of plastic solids but the action of the plastic ice under a complexity of geologic conditions.

Drumlin forms and observed relations. The interaction of the physical and geologic factors noted above has produced a great variety of drift forms which we may include under the general class of *ice-molded*, or *drumlinized drift*. These forms have been described or noted in the writing above, but it is well to name them here for comparison.

1 Domes or mammillary hills and low broad mounds.

2 Broad oval drumlins [pl. 7].

3 Oval drumlins of high relief [pl. 11].

4 Long oval drumlins, commonly bolder on the north or struck end; the dolphinback or whaleback hills [pl. 14].

5 Short ridge drumlins [pl. 6].

Plate 28

Endwise view of drumlins 3 miles southeast of Syracuse. Looking east of south from St Vincent de Paul Church, Syracuse. These drumlins are the southeast extremity of the drumlin area.

Plate 29

Mormon hill. Drumlin 4 miles south of Palmyra. End view looking south. Compare plate 30

Plate 30

Mormon hill. Drumlin 4 miles south of Palmyra. Side views taken from same point. Compare plate 29. Upper, view looking northeast; lower, view looking east

6 Long ridge drumlins. This includes two extreme varieties of form: (*a*) the long broad ridges or rolls or gentle swells which are not generally recognized as belonging in the drumlin class, and commonly fail of representation on the contoured maps [pl. 18]; (*b*) the small, close-set, parallel ridges which lie as minor moldings between the larger and conspicuous ridge drumlins, or those which form the attenuated edge of a drumlin belt [pl. 13].

7 Abrupt struck slopes [pl. 30, 35, 40].

8 Low or gentle struck slopes [pl. 22, 23].

9 Sharp crested hills with steep, or even concave, side slopes [pl. 29.]

Many occasional or peculiar forms and characters might be noted but they are not regarded as genetically important.

The relationships of the several forms are not so definite or exclusive as might be expected, though further study may discover new facts. However, there are certain broad relations of distribution and association which will be restated here.

1 The drumlin area is practically restricted to the north-facing or ice-opposing slope.

2 The region of greatest development of drumlins is on the low Ontario plain, which is nearly level.

3 The greatest development lies over the greatest thickness of the Salina shales, or where the drift is most clayey and adhesive.

4 The predominant drumlin area lies where the ice flow was east of south and at a high angle with the general southwesterly flow.

5 The somewhat exclusive development of the long and low ridges (6 *a*) is in the northwest corner of the State where the ice had only the one direction (southwest) of flow, but where there was less volume of clayey drift because less thickness of eroded shales.

6 The individual drumlins are not placed in any orderly sequence or regular disposition, but are irregularly spaced.

7 Within the same belt of drumlins or what is regarded as a formational unit the south forms or those nearer the ice border are more attenuated, while the north forms or those under the deeper ice are broader.

8 A belt of moraine drift lies in front of the attenuated border of the drumlin belt.

9 The greater hight of the drumlins, their steepness of slope and

regularity of form seem to occur in the middle of the belt and to characterize the maximum work of the constructive process.

10 Steep struck slopes seem to be more commonly associated with the steep and long ridges; while the low struck slopes pertain to the lower and broader forms.

Relation to moraines

The precise relation of the several drumlin belts to the terminal (recessional) moraines can not be fully stated until further careful study has been given to the moraines, but a few interesting facts can now be given.

If the drumlins specially represent the more vigorous movement of the bottom ice during episodes of either frontal advance or halts in the frontal recession then each drumlin belt should correlate with a frontal moraine.[1] Such relationship seems definite for the central or main drumlin belt, the Oakfield-Syracuse series, in the stretch from Syracuse westward as far as the meridian of Rochester. Where the drumlins fade out to the attenuated forms, from Auburn westward to Geneva, a distinct moraine lies 2 or 3 miles in front, on the south [pl. 13]. Remnants of the moraine mark its course eastward to Split Rock, southwest of Syracuse, but in the Split Rock district the ice front was swept by rivers of ice border drainage and the ice-rafted drift was largely dropped into the grasp of the streams. West of Geneva the same relation of drainage to the ice front is very pronounced. A remarkable series of strong river-cut channels extending from northwest of Batavia eastward to Phelps swept the ice margin and removed most of the terminal drift, though some remnants are left, sufficient to prove its position.[2]

The interesting fact in this connection is that the drumlins of the main series reach in full strength up to the north bank of these channels [pl. 9, 11, 14] and there abruptly end. The drainage channels do not represent the forward position to which the ice would have reached with no interference (or the location of the moraine

1 The theory is now held by glacialists that the front of the continental glacier receded by oscillation, a succession of retreats and lesser readvances, and that the stronger moraines were accumulated at the ice margin during the culmination of the advances. The successive moraines in any given area are thus supposed to mark the successive readvanced positions of the ice front. For this subject see specially the writings of F. B. Taylor, "Moraines of Recession and Their Significance in Glacial Theory" [Jour. Geol. 1897. 5: 421-66].

2 The description of these glacial river channels will be found in another bulletin of the State Museum, under the title, "Glacial Drainage between Batavia and Syracuse."

Plate 31

Drumlin profiles blending in smooth horizon line. Looking southwest from 1¼ miles southwest of Wayne Center. At least 12 drumlins in the view

Plate 32

Ridge drumlins 4 miles southeast of Clyde. Looking northwest from north and south road, 1 mile north of county line. Land of W. H. Lawrence. Three ridges lie in the background

Large and small ridge drumlins, 1 mile east of Lyons. Looking southwest. Land of George Warucke. Two minor ridges, in middle view, lying between two major ridges

in such case) but a belt further iceward, the rivers truncating the thinner border of the ice sheet.

Moraine belts like the Auburn and Seneca Falls moraine represent only the superglacial and higher englacial drift, carried to and passively dropped at the extreme margin, while, pari passu, the drumlins were forming beneath the ice in the rear of the moraine, from the subglacial (and perhaps the lower englacial) drift.

When recession of the ice front again occurred, either by increased melting or by diminished ice movement, the superior drift was quietly lowered on the drumlin territory, falling chiefly in the hollows between them. Not infrequently we find a patch of irregular surface among the drumlins which can readily be discriminated and mapped as moraine, and rarely this may obscure the half buried drumlins [*see* p. 412] as in the Junius kame area. Sometimes the volume of moraine drift increases to the north and is so distributed as to give a decided morainal surface among the northern drumlins, as in the Walworth district [pl. 15]; or else the next succeeding moraine on the north laps on to the north edge of the drumlin belt, as in the Oswego district [pl. 6].

At the termination of heavy lines of glacial drainage, during both the active and the stagnant episodes, heavy deposits of water-laid drift (kame moraines) accumulated, as the Junius, Victor, Irondequoit valley, Mendon, and other kame areas.

Theoretically the moraines should be weak where the drift was left in drumlin form, and the facts seem in accord. In the stretch from Batavia to Syracuse the moraine belts are weak, though a few kame areas are strong.

Special features

Syracuse island masses. These remarkable groups are partly shown in plates 9 and 10 and are fully shown on the Syracuse and Baldwinsville sheets. They are partly bounded by river channels of the latest glacial drainage cut in Salina shales. North of Warners [pl. 9] is an example of such drumlin massing not surrounded by river valleys. In the more striking of these groups there is a cumulation or increase of hight toward the center which is a peculiar feature. If these drumlin masses have a core of rock reaching above the Salina shales, which form their base up to 500 feet or more, it has not been found, though it is not improbable for the more northerly groups.

The isolation of these groups can not be entirely due to channeling by the later drainage because the drumlins which cap the island-like rock masses are not themselves eroded, but lie wholly above the plane of the river work. It appears as if the ice rubbing did not touch the lower levels but was confined to higher planes. The forms do not seem explicable on the postulate of a single ice invasion with one episode of correlating ice border drainage. The relation of the drumlins to the erosion, and the character and direction of the stream courses [pl. 9, 10] suggest a complicated history. We have here only one of several groups of phenomena which argue for more than one ice epoch with their correlated stream work.

Montezuma island groups. Plate 12 shows the largest of several groups of drumlins which rise out of the marshes that occupy the low ground north of Cayuga lake. These are not conical or cumulative masses like those described above, but isolated groups, of irregular forms and sizes, even down to single drumlins. In the Montezuma district these groups or individuals rise out of the broad marshes as if half drowned. A few small knolls are mapped about the borders of the marshes, like the summits of nearly buried drumlins, but it does not seem likely that the absence of drumlins over wide tracts could be due to entire burial of drumlins under lake and vegetal accumulations. More likely the marshes are only the low areas similar to others at higher levels that are destitute of drumlins. This leads to the next topic.

Nondrumlin areas: open spaces. The broad swamp tracts, like the Montezuma marshes, belong in this category as well as more elevated and drier areas. An example of the latter lies north of Clyde, where a large tract in the center of the Clyde quadrangle shows white on the topographic sheet. The east edge of this tract is shown in plate 3, figure 3. This surface was under Iroquois waters but the lack of drumlins is certainly not due to their destruction. Evidently they were not formed in this tract. The reason is obscure, since the area is irregular in shape with scattering drumlins on all meridians and close set on the west, east and south. This absence of drumlins over considerable tracts in the midst of heavy development is more difficult of explanation than the formation of the drumlins themselves

These puzzling features lie in the region of deep drift filling of ancient valleys, the northward continuation of those now holding

Plate 34

Eroded north end of drumlin, 2 miles southeast of Clyde. Looking west of south. Erie canal and railroads in middle view

Plate 35

Abrupt north ends of drumlins, 1½ miles southeast of Clyde. Looking southeast

North end of drumlin, 1/3 mile west of Savannah. Looking south from New York Central Railroad. The end is eroded obliquely by Iroquois waves

the finger lakes, and chiefly in the north and south depression of Sodus bay and Cayuga lake. The nondrumlin spaces can not be regarded as having been occupied by stagnant ice during the drumlin-shaping episode since they are surrounded by drumlins, and are comparatively free from moraine. They can not represent areas of ice movement too vigorous for drumlin accretion or shaping as the ice along the line of flow must have had a practical equality of motion. There is no reason for supposing that there was any lack of drift, since an immense quantity is piled in drumlins immediately southward. The location and distribution of the spaces, as well as the drumlins themselves, are such as to oppose the idea that the drumlins represent an original morainal distribution of earlier drift. We have to recognize the probable equality of the drumlin and nondrumlin loci in the elements of depth and pressure of the ice, in its impact and velocity of motion and in its burden of drift

The following suggestions are offered toward the explanation of these puzzling features. In the region of deep valley filling it is possible that some depressions were below the average level and consequently below the plane of the more vigorous thrustal motion, and it is conceivable that a plane of shearing might have been established above the depressions. Shearing once established would probably be unfavorable to the initiation of drumlins, as the drumlins imply some degree of local drag in the bottom ice during the time of accretion or shaping of the forms. The lowest of the open spaces have been partly filled with lake silts and stream detritus and vegetal accumulation, and some are still partly under water, as the Montezuma marshes; but the spaces north of Clyde do not appear to have been leveled by postglacial agents. The existence of well developed drumlins within or on the borders of open spaces might be due to accretion on existing obstructions, while the shearing tendency discouraged initiation of new masses.

A second suggestion is based on the idea of a complex glacial history. An earlier ice invasion may have localized and heaped the drift in part, while the interglacial stream work carved broad channels through the area, which the latest ice work has not wholly obscured.

Channels among the drumlins. These are connected with or blend into the open spaces discussed above and are part of the same problem. They are specially developed between Fairport and

Lyons; between Montezuma and Syracuse; and along the Seneca river. Those with direct east and west course were occupied by the latest ice border drainage but apparently were not wholly produced by it. These features appear on the Macedon, Palmyra, Weedsport and Syracuse sheets, and a suggestion of them is shown in plates 9–12. The channels all lie in Salina shales and possibly they have some genetic relation to the erodible nature of the rocks.

The existence and location of these low, continuous passages are strikingly emphasized by the remarkable windings of even the larger streams, Seneca river for example. The northward turns which this wayward stream makes east of Savannah, and more strikingly from Cross lake (an open tract) around by Baldwinsville and south to near Onondaga lake, must have been found open or the stream would have taken the direct eastward passages that are almost as low today even without any postglacial erosion. A smaller illustration is found in the case of Ganargua creek east of Palmyra, where it deserts the open glacial stream course and wilfully turns north around by East Palmyra in a constricted and uninviting pass, and repeats the act with less excuse northeast of Newark.

One suggestion for these open passages, which were certainly left open by the ice removal and were not cut by postglacial erosion, is that they were made by subglacial drainage, either under free flow or under hydraulic pressure. This seems reasonable for south-leading passages like those northeast of Clyde, and even for north-leading channels of gentle grade, like the valley of Dead creek in plate 10; but it is not satisfactory for the east and west passes which were transverse to the ice movement.

Another suggestion is that the passes were cut by glacial drainage of an earlier ice sheet, with modification by the subsequent interglacial erosion. It seems probable that the complex history of the region may involve such episodes and activities; or that perhaps the oscillations of the last (Wisconsin) ice sheet were sufficiently extensive to produce the phenomena. The difficulty under this theory is to explain why the drumlin-making work of the ice did not rub the channels full of drift. This difficulty is of the same kind, however, as the absence of drumlins over interdrumlin tracts. In the case of the deep channels around the Syracuse island masses it might be suggested that possibly during the latest stage the channels were occupied by stagnant ice over which the drumlin-forming layers

Plate 37

Eroded drumlin, west edge of Savannah. Looking south from New York Central Railroad. The north end cut obliquely by Iroquois waves

Plate 38

Drumlin eroded at south end by Iroquois waves. 2 miles west of Savannah; looking northeast. Note the house in the orchard, and the abrupt notch in the drumlin. The crest of the drumlin was originally at about the top of the barns. Compare plate 39

Plate 39

South ends of drumlins 2 miles west of Savannah. End view of drumlin shown in plate 33. Looking north from tracks of New York Central Railroad

moved or slid by shearing; but this could hardly apply to the Clyde and Montezuma districts, where the drumlin forms lie at the lowest levels.

A modification of the subglacial drainage theory offers some help. It seems probable that the last stage of the glacier in this region left an extensive border tract of stagnant ice, and that unequal melting due to a variety of causes produced detached blocks or tracts of ice around or among which the copious glacial waters excavated many channels. The subglacial drainage combined with the later inter-ice block drainage may largely account for the peculiar features. In this connection it must be understood that the attitude and elevation of the land surface of the region has changed to some extent since the features were made; and that the lakes and sluggish waters, aided by organic growths, have partially filled the low grounds.

Summary

Age of the drumlins. The form and relations of the drumlins in the Pulaski district, due to the change of direction in the ice flow proves that they were shaped during the latest phase of the ice work in that locality, and not during any earlier stage. The same conclusion is reached by the theoretical considerations and enforced by the facts of observation for the entire drumlin area.

The peculiar distribution of the drumlins and their orientation prove that they were shaped by the spreading flow of the semistagnant ice mass reposing in the Ontario basin. The correlation of moraines and of ice border drainage channels with the attenuated edge of the main belt of drumlins indicates that the drumlins were formed beneath the border of the ice sheet. This correlation of the drumlin shaping with the latest work of the ice in the drumlin region has been noted in other drumlin areas, as Wisconsin, Massachusetts, Ireland and Germany. The fact seems to be sufficiently established that the alinement and shaping of the drumlins was given under the waning border of the ice sheet, at least in the case of the continental glaciers.

Thrust motion of the ground contact ice. Drumlins are shaped by the sliding movement of the lowest ice, that in contact with the land surface. This fact implies that the whole thickness of the ice sheet participated in the motion. Such motion was not due to gravitational stress on the ice mass over the drumlin area, because the

general slope of the drumlin area is up hill, but was produced by an effective thrust on the marginal ice by the pressure of the rearward mass. As the ice sheet thinned by ablation there came a time when the drift-loaded ice in contact with the ground was subjected to less vertical pressure and to relatively greater horizontal pressure by the deep ice in the rear, and was *pushed forward, bodily.* In this fact is believed to lie the key to drumlin formation.

It does not follow that drumlins must always have been formed where the bottom ice had a sliding motion, as several other conditions are probably requisite, but it seems quite certain that long-continued and vigorous horizontal thrust is the prime necessity. Such thrustal movement would be effective only where a border of the ice sheet was backed by a thick or vigorously pushing rearward mass. The combination of conditions requisite for effective thrust movement over a belt of country and for the considerable time necessary to build up the drumlins may be rare. It does not seem so strange that drumlins are uncommon features of the drift when we add to the requisite dynamic factors mentioned above the several others which are doubtless directly concerned with the drumlin formation.

As a working hypothesis it may be assumed that wherever the ground contact ice had a vigorous movement of some duration it should be indicated by the molding of the ground surface, specially where that surface is comparatively smooth and composed of drift or soft rocks. The form and degree of the ice molding would vary according to the strength and adjustment of the several factors. An application of this idea can be made to the region under present study.

Well marked drumlins are not found on the high ground east of Seneca lake, and are wanting on the low ground east of Syracuse. The explanation seems to lie in the relationship of the larger topography to the movement of the ice sheet. When the glacier was deep over the Finger lakes region the bottom of the ice in the drumlin area was probably quiescent and served as the bridge over which the upper ice moved by gravity; the repose of the lower ice probably being due to the opposing land slope and to the large volume of drift which the ice had incorporated. Over the nearly level area north of the Finger lakes the waning of the ice sheet finally subjected the ground-contact ice to a vigorous and long-continued horizontal thrust with consequent sliding motion. But in the adjacent

Plate 40

Superposed drumlin. Cushman hill, 2½ miles northwest of Scottsville. Looking south of west

Superposed drumlin. Hosmer hill, 4 miles northwest of Scottsville.
Upper, distant view, looking southeast ; top drumlin in forest. Lower, near view, looking west of north

Plate 42

Superposed drumlin. Martin hill 1 mile east of West Rush. Looking south of east

district of low ground northeast and east of Syracuse (over Oneida lake, Canastota, Oneida and eastward) we have an illustration of nonmotion of the ground-contact ice. The almost bare hills of soft Vernon shales in the region of Canastota have not been subjected to the rubbing action of the ice from any direction. In form these clay hills closely resemble moraine drift, and with their slight veneer of glacial rubbish would at first be mistaken for moraine by even the experienced geologist. This surface would have been sensitive to any ice movement, the absence of which is explained as follows: While the ice sheet was thick the flow was from the northward and the ground-contact ice in this district, lying in the broad depression between the Adirondack massive on the north and the high plateau on the south, was quiescent. With the waning of the ice sheet it disappeared from the high ground to the north so that the stagnant mass resting on the Canastota-Oneida district was not subjected to any push from the northward. During the closing or drumlin-making phase of the ice work in the Ontario basin the radially spreading ice of the Ontarian mass did not reach this district. In brief, the ground-contact ice over the Canastota-Oneida district, although occupying a low tract on the edge of the drumlin area, did not at any time receive horizontal impulse but was deserted and allowed to quietly melt away, or perhaps to be lifted and rafted off in the glacial lake waters which fronted the glacier. The extreme reach of the drumlin-forming activity in the Syracuse district was in the form of a tongue or wedge of moving ice which was thrust southeastward along the Onondaga lake depression and over the site of Syracuse, ending a few miles southeast of the city; and affecting only the higher ground, or the summits of the island masses.

Origin. It is certain that the New York drumlins were constructed or built up by a plastering-on process. The ice did not drop its drift burden in the depressions or low places but plastered it on the obstructions. The plastic and adhesive character of the shale-derived drift of central New York is probably one factor accounting for the great number, hight and shape of the drumlins of that district.

The rocdrumlins, or shale hills with the peculiar drumlin form, being shaped by a moderate amount of erosion of the soft rock might suggest, at first thought, that erosion was the main factor in drumlin formation. Possibly it may be in some regions; but vig-

orous abrasion of hard rocks would scarcely be consistent with drumlins in the same locality.

The building of drumlins by the plastering process was coincident with a rubbing off and shaping effect. As masses or hills the drumlins were produced by accretion of the drift, but their peculiar form is due to the erosional factor. The whole process may be compared to the work of the sculptor on a clay model: a plastering on and rubbing away. The accretion was due to the greater friction between clay and clay than between the clay and ice. The hills of accretionary drift resisted the ice impact and rasping effect just as did the hills of shale. The form possessed by both classes of hills is that which opposed successful resistance to the ice erosion, and the least resistance to the ice movement.

Dynamics. It seems evident that in the typical drumlin area the ice did not move as a solid mass or even in wide sections, for such motion should produce a planing or leveling effect, such as is illustrated in the Niagara-Genesee prairie [pl. 19]. The drumlins are proof of a plastic flow or yielding of the ice; while the long, straight ridges suggest that the ice was pushed in comparatively rigid bolts or prisms that wavered and shifted.

In the balancing and adjustment of the several dynamic factors in the drift-burdened ice the two opposing forces of rigidity and plasticity seem to be the most important. The amassing of the drift into drumlin form, or at least the nonremoval of the hills, implies that the depth of ice and the vertical pressure were so moderate as to allow the plastic ice to override and adapt itself to the hills, while at the same time the whole sheet of ice was sufficiently rigid to move under horizontal thrust.

Judging from the facts and theoretic mechanics noted above it would seem that the drumlins represent the short lines of temporarily diminished pressure and of lagging flow. These lines of variable pressure and motion, though close set in the dominant drumlin area, must have been discontinuous, short and constantly shifting. Drumlins could not have been determined, as regards location at least, by external influences, as atmospheric agencies above or topographic and geologic features beneath, but must have been produced by the interaction of the mechanical factors resident within the ice itself, the latter moving as a plastic solid. Their initiation may have been

Plate 43

Erosion cliff in drumlin; Lake Ontario shore. "Chimney bluff," 2 miles northeast of Sodus bay. Looking southeast

Foliated drumlin structure. "Lake Bluff," Sodus bay, shore of Lake Ontario. Looking southeast

Plate 45

Foliated drumlin structure. "Blind Bay bluff," shore of Lake Ontario, 5 miles northeast of Sodus bay. Looking south

due to some obstruction beneath the ice or to a local amassing of drift by the ice itself.

Drumlin forms. The breadth of the Oakfield-Scottsville-Palmyra-Syracuse drumlin belt or series, which is supposedly a unit in time of formation, is about 20 miles wide in the central part. The eastern Ontario series has about the same width on the Fulton sheet.

If the northern and broader drumlins in each belt were mostly built contemporaneously with the southern attenuated forms, as seems most probable, then we may assign a few of the conditions that were responsible for the different forms.

The northern, broader and more widely separated drumlins, such as those at Sodus [pl. 4], were certainly under greater vertical pressure on account of the greater depth of the ice. This might have given greater potential plasticity, though the effective plasticity and the differential movement might have been less than in the central part of the belt. On the other hand the attenuated drumlins [pl. 13] under the thinner ice near the border of the sheet would be subject to less vertical pressure. Here the ice had less frontal resistance and therefore freer movement; it was less burdened with drift, having already built the drumlins in the rear; and probably it had less effective plasticity and less differential movement. In other words, the attenuated, border forms of the drumlin belt were formed beneath ice moving with relatively greater freedom, greater relative rigidity, and with more uniformity and continuity.

The culmination of the drumlin-making process seems to have been in the middle of the belt, where the several dynamic factors were well balanced and were working together at the maximum of efficiency. There the drift was abundant and plastic; the rigidity and the plasticity of the ice were active but well balanced; and the differential flow was at its maximum, that is to say, the ice was not moving in long, rigid bolts or wide masses but in short and wavering prisms.

The very long and flat ridges characteristic of the Niagara-Genesee prairie [pl. 18, 19] seem to be the product of steady and long-continued movement of thicker and more rigid ice than that which built the shorter, steeper and crowded drumlins in the middle of the State. The ice probably had less burden of drift, less differential flow and less effective plasticity. The effect was similar to the production of

the small, linear forms on the attenuated drumlin border in the Waterloo-Seneca Falls district, but the work was on a much larger scale. The direction of the drift molding in the western district, it should be noted, is that of the prevailing direction of the continental glacier over the region.

Depth of the drumlin-making ice. We have no conclusive facts on this topic but some suggestive data. The relationship of the Waterloo-Seneca Falls moraine, and of the ice-border drainage channels on the west, to the south edge of the main drumlin series seems to locate definitely the edge of the ice sheet during that episode. North of the Finger lakes region the receding ice front was continuously bathed by glacial lake waters, and the moraines were laid down under water. The moraine above named seems to correlate with certain deltas and outlet channels to the east. If the correlation is correct the water in which the moraine was deposited had a surface altitude, present elevation, of about 900 feet. The depth of water at the ice front was therefore about 400 feet, since the moraine tract lies at about 500 feet.

As the moraine is weak, largely because the drift load had been incorporated into the drumlins in the rear, we may assume that the ice was not heavily anchored in the lake water by its load of rock rubbish. In order to retain its place under the buoyancy of the waters it must have been at least 450 feet thick, or 50 feet above the water. Taking this as the minimum depth of ice at the glacier margin and assuming a surface slope of 30 feet to the mile, the elevation of the surface of the glacier over Clyde, 12 miles north of the moraine, would be (950+30x12) about 1310 feet. Since the general base of the Clyde drumlins is about 400 feet elevation the depth of ice in the center of the drumlin belt was about 900 feet. The drumlins are less than 200 feet high, which gives a depth over their tops of more than 700 feet of ice. This is merely suggestive.

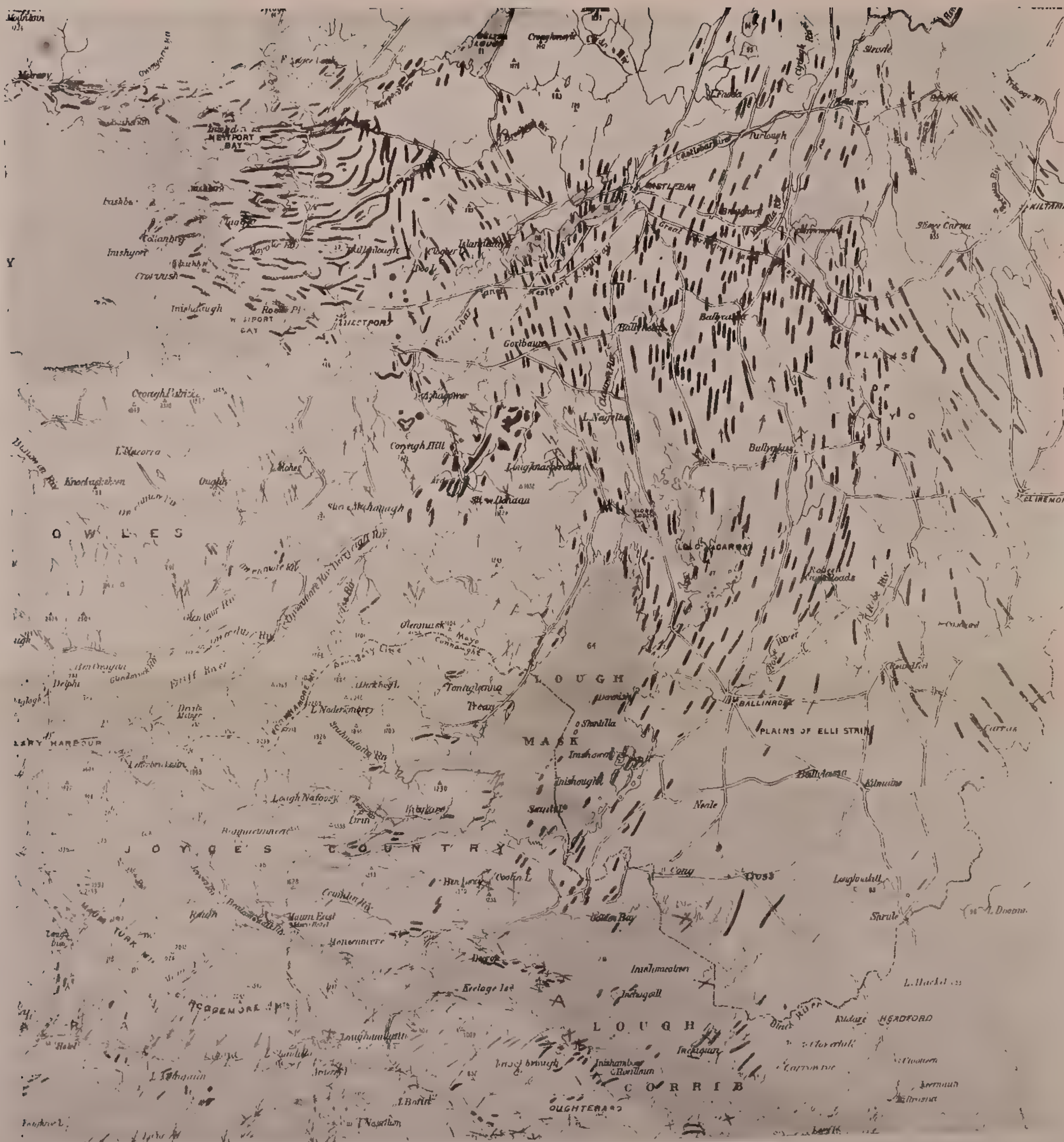
Complex history. It is very likely that there are undiscovered and unsuspected elements in the Pleistocene history of central-western New York, and that it is much more complicated than it now appears. Probably there has been more than one epoch of ice invasion and retreat along with heavy erosion by glacial and non-glacial waters. As we see the drumlins today they represent in their forms, in each series, the latest ice work; but it is quite possible that some of them were related to an earlier ice sheet.

Plate 46

Foliated drumlin structure. "Nigger hill," 4 miles west of Sodus point, shore of Lake Ontario. Looking southwest

Plate 47

Plate 47



Drumlins of Iar-Connaught, Ireland
Reduced from portion of the map published by Kinahan and Close

Drumlins of Ireland

The remarkable series of drumlins described by Kinahan and Close[1] have a special interest in this study, as they are the type forms, produced by local glaciation in a far distant land, and are strikingly similar in essential features to our New York forms.

The distribution of the principal group of the Irish drumlins is shown on plate 47 which is a copy, in reduced size, of a portion (upper right corner) of the original map by the Irish authors. The direction of flow of the ice current that produced this group of drumlins was toward the north, and spreading specially to the west, toward Clew bay; but in other districts the few drumlins have other directions, corresponding to the radial flow of the ice away from the local center of accumulation. The arrangement of the drumlins in curving lines of the ice flowage is very striking, and not easily explained except by the constructional theory of their genesis.

The drumlins are described as occurring only on low ground, and even forming islands and shoals in the sea (Clew bay). Their absence from some parts of the low plain is noted as a feature not understood.

The up stream ends of the drumlins (with reference to the ice currents) are noted as the blunt ends, although this is not stated as a constant feature, since the hills have suffered some erosion by marine submergence.

The "parallel shaping" of the general ground surface in the drumlin district was observed.

The extreme hight of the drumlins is given as 180 feet, in striking accordance with the New York forms. Another important observation is the "observable uniformity in size in the same neighborhood." Concerning length it is noted that several of the drumlins are 2 miles long; and that the mean length is not less than ½ mile.

With reference to the composition the authors say that the drumlins "consist of stiff, unstratified boulder clay, containing well blunted and scratched stones and blocks." "They have been

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1 Kinahan, G. H. & Close, H. M. General Glaciation of Iar-Connaught and its Neighborhood, in the Counties of Galway and Mayo. With map. Dublin 1872.

For the favor of seeing this somewhat rare pamphlet and using its matter and map the writer is indebted to Mr F. B. Taylor.

unquestionably formed by some operation different from, and antecedent to, that which produced the water-arranged gravels and eskers. Deposits of water-formed gravel, etc., clearly of later date, often occur in the lower ground between the drumlins, and even banked up against them."

The authors apparently regarded their drumlins as constructional forms and did not regard the matter as needing discussion, since they refer to the origin of the drumlins only incidentally, as follows:

"No agent which can not do both kinds of work, rock-scoring and drumlin-heaping, can be proposed as having caused them" [p. 9].

". . . And it has formed the drumlins by an operation evidently similar to that by which a stream of water often makes longitudinal ridges of sand in its bed."

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The following list of writings in English relating to drumlins is not exhaustive, and it is possible that some valuable references have been overlooked, specially of foreign authors. Numerous incidental references have been purposely omitted. Outside of English the literature seems scanty, but an important paper in German is noted on page 394.

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New York State Education Department

New York State Museum

JOHN M. CLARKE, Director

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Report for 1904. 138p. 20*c*. 1905. 102p. 23pl. 30*c*. 1906. 186p. 41pl. 35*c*.

Geologist's annual reports 1881–date. Rep'ts 1, 3–13, 17–date, O; 2, 14–16, Q.

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The annual reports of the original Natural History Survey, 1837–41, are out of print.

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Bound also with museum reports 21–date of which they form a part; the first Botanist's report appeared in the 21st museum report and is numbered 21. Reports 21–24, 29, 31–41 were not published separately.

Separate reports for 1871–74, 1876, 1888–96 and 1898 (Botany 3) are out of print. Report for 1897 may be had for 40c; 1899 for 20c; 1900 for 50c. Since 1901 these reports have been issued as bulletins [*see* Bo 5–9].

Descriptions and illustrations of edible, poisonous and unwholesome fungi of New York have also been published in volumes 1 and 3 of the 48th (1894) museum report and in volume 1 of the 49th (1895), 51st (1897), 52d (1898), 54th (1900), 55th (1901), 56th (1902), 57th (1903) and 58th (1904) reports. The descriptions and illustrations of edible and unwholesome species contained in the 49th, 51st and 52d reports have been revised and rearranged, and, combined with others more recently prepared, constitute Museum memoir 4.

Museum bulletins 1887–date. O. *To advance subscribers, $2 a year or $1 a year for division* (1) *geology, economic geology, paleontology, mineralogy; 50c each for divisions* (2) *general zoology, archeology and miscellaneous,* (3) *botany,* (4) *entomology.*

Bulletins are also found with the annual reports of the museum as follows:

Bulletin	*Report*	*Bulletin*	*Report*	*Bulletin*	*Report*	*Bulletin*	*Report*
G 1	48, v.1	Pa 1	54, v.1	En 7–9	53, v.1	Ar 2	51, v.1
2	51, v.1	2,3	" v.3	10	54, v.2	3	52, v.1
3	52, v.1	4	" v.4	11	" v.3	4	54, v.1
4	54, v.4	5, 6	55, v.1	12, 13	" v.4	5	" v.3
5	56, v.1	7–9	56, v.2	14	55, v.1	6	55, v.1
6	57, v.1, pt 1	10	57, v.1, pt 1	15–18	56, v.3	7	56, v.4
7–10	58, v.1	11–14	58, v.3	19–22	57, v.1, pt 2	8, 9	57, v.2
Eg 5, 6	48, v.1	Z 3	53, v.1	23, 24	58, v.5	10,11	58, v.4
7	50, v.1	4	54, v.1	Bo 3	52, v.1	Ms 1, 2	56, v.4
8	53, v.1	5–7	" v.3	4	53, v.1		
9	54, v.2	8	55, v.1	5	55, v.1	*Memoir*	
10	" v.3	9	56, v.3	6	56, v.4	2	49, v.3
11	56, v.1	10	57, v.1, pt 1	7	57, v.2	3, 4	53, v.2
12, 13	58, v.2	11, 12	58, v.4	8	58, v.4	5, 6	57, v.3
M 2	56, v.1	En 3	48, v.1	Ar 1	50, v.1	7	" v.4
3	57, v.1, pt 1	4–6	52, v.1				

The figures in parenthesis in the following list indicate the bulletin's number as a New York State Museum bulletin.

Geology. **G1** (14) Kemp, J. F. Geology of Moriah and Westport Townships, Essex Co. N. Y., with notes on the iron mines. 38p. 7pl. 2 maps. Sep. 1895. 10*c*.

G2 (19) Merrill, F. J. H. Guide to the Study of the Geological Collections of the New York State Museum. 162p. 119pl. map. Nov. 1898. [50*c*]

G3 (21) Kemp, J. F. Geology of the Lake Placid Region. 24p. 1pl. map. Sep. 1898. 5*c*.

G4 (48) Woodworth, J. B. Pleistocene Geology of Nassau County and Borough of Queens. 58p. il. 9pl. map. Dec. 1901. 25*c*.

G5 (56) Merrill, F. J. H. Description of the State Geologic Map of 1901. 42p. 2 maps, tab. Oct. 1902. 10*c*.

G6 (77) Cushing, H. P. Geology of the Vicinity of Little Falls, Herkimer Co. 98p. il. 15pl. 2 maps. Jan. 1905. 30*c*.

G7 (83) Woodworth, J. B. Pleistocene Geology of the Mooers Quadrangle. 62p. 25pl. map. June 1905. 25*c*.

G8 (84) —— Ancient Water Levels of the Champlain and Hudson Valleys. 206p. 11pl. 18 maps. July 1905. 45*c*.

G9 (95) Cushing, H. P. Geology of the Northern Adirondack Region. 188p. 15pl. 3 maps. Sep. 1905. 30*c*.

G10 (96) Ogilvie, I. H. Geology of the Paradox Lake Quadrangle. 54p. il. 17pl. map. Dec. 1905. 30*c*.

G11 (106) Fairchild, H. L. Glacial Waters in the Erie Basin. 88p. 14pl. 9 maps. Feb. 1907. 35*c*.

G12 (107) Woodworth, J. B.; Hartnagel, C. A.; Whitlock, H. P.; Hudson, G. H.; Clarke, J. M.; White, David; Berkey, C. P. Geological Papers. 388p. 56pl. map. May 1907. 90*c, cloth.*

Contents: Woodworth, J. B. Postglacial Faults of Eastern New York.
Hartnagel, C. A. Stratigraphic Relations of the Oneida Conglomerate.
—— Upper Siluric and Lower Devonic Formations of the Skunnemunk Mountain Region.
Whitlock, H. P. Minerals from Lyon Mountain, Clinton Co.
Hudson, G. H. On Some Pelmatozoa from the Chazy Limestone of New York.
Clarke, J. M. Some New Devonic Fossils.
—— An Interesting Style of Sand-filled Vein.
—— Eurypterus Shales of the Shawangunk Mountains in Eastern New York.
White, David. A Remarkable Fossil Tree Trunk from the Middle Devonic of New York.
Berkey, C. P. Structural and Stratigraphic Features of the Basal Gneisses of the Highlands.

G13 (111) Fairchild, H. L. Drumlins of New York. 58p. 28pl. 19 maps. July 1907. 35*c*.

—— Later Glacial Waters in Central New York. *Prepared.*

Cushing, H. P. Geology of the Theresa Quadrangle. *In preparation.*

—— Geology of the Long Lake Quadrangle. *In press.*

Berkey, C. P. Geology of the Highlands of the Hudson. *In preparation.*

Economic geology. **Eg1** (3) Smock, J. C. Building Stone in the State of New York. 152p. Mar. 1888. *Out of print.*

Eg2 (7) —— First Report on the Iron Mines and Iron Ore Districts in the State of New York. 6 + 70p. map. June 1889. *Out of print.*

Eg3 (10) —— Building Stone in New York. 210p. map, tab. Sep. 1890. 40*c*.

Eg4 (11) Merrill, F. J. H. Salt and Gypsum Industries of New York. 92p. 12pl. 2 maps, 11 tab. Ap. 1893. [50c]
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Eg9 (35) Ries, Heinrich. Clays of New York; their Properties and Uses. 456p. 140pl. map. June 1900. $1, *cloth*.
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Eg11 (61) Dickinson, H. T. Quarries of Bluestone and other Sandstones in New York. 108p. 18pl. 2 maps. Mar. 1903. 35c.
Eg12 (85) Rafter, G. W. Hydrology of New York State. 902p. il. 44pl. 5 maps. May 1905. $1.50, *cloth*.
Eg13 (93) Newland, D. H. Mining and Quarry Industry of New York. 78p. July 1905. 15c.
Eg14 (100) McCourt, W. E. Fire Tests of Some New York Building Stones. 40p. 26pl. Feb. 1906. 15c.
Eg15 (102) Newland, D. H. Mining and Quarry Industry of New York. 2d Report. 162p. June 1906. 25c.
Eg16 (112) Mining and Quarry Industry 1906. 82p. July 1907. 15c.
Newland, D. H. & Hartnagel, C. A. The Sandstones of New York. *In preparation*.
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—— Dictyonine Hexactinellid Sponges from the Upper Devonic of New York.
—— The Water Biscuit of Squaw Island, Canandaigua Lake, N. Y.
Simpson, G. B. Preliminary Descriptions of New Genera of Paleozoic Rugose Corals.
Loomis, F. B. Siluric Fungi from Western New York.

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Clarke, J. M. New Agelacrinites.
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2 Hall, James & Clarke, J. M. Paleozoic Reticulate Sponges. 350p. il. 70pl. 1898. $1, *cloth*.
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